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THE ROMANCE OF THE HUMAN BODY

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THE ROMANCE OF
THE HUMAN BODY

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LONDON
WELLS GARDNER, DARTON & CO., LTD.
3 AND 4 PATERNOSTER BUILDINGS, E.C.4
AND 44 VICTORIA STREET, S.W.1

First Edition . . 1917
Second Edition . 1919

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To

MY FRIENDS

RICHARD CAMERON

AND

Principal Sir GEORGE ADAM SMITH

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THE ROMANCE OF THE HUMAN BODY

CHAPTER I

ATOMS AND CELLS

'I am sure we should all be as happy as kings,
The world is so full of a number of things.'
STEVENSON, *Child's Garden of Verses.*

The world is full of a number of things. When we look around us, we discriminate millions of different objects,—men and flies, lilies and fir trees, oceans and stars. Our eyes and minds naturally separate out various things from the composite universe. And we can separate any field of vision into objects in various ways: we can divide large things into smaller things; we can bind small things into larger things; we can shatter the world to bits and then 'remould it to our heart's desire.' To the *infant*, perhaps, the world is just a blur of mixed impressions—'one big blooming buzzing confusion'; but the initial step to thinking and doing is the individuation of the world. It is the particulate conception of the universe, as seen by the eyes and felt by the touch, that renders thought and action possible. Such a conception of the world around him every reasonable man must have.

Men with analytical minds cannot stop discriminating: they must go deeper and deeper in their individuation and comparison; and scientists soon began to study not only the obvious visual and tactile characters of things but their more occult chemical and physical properties. Such analytic investigation led to discoveries, and to new separations of the world. It was found out that things that seemed to consist of only one substance were really built up of two or more separable and dissimilar substances. Thus it was found out that red substance, known as mercuric oxide, could be divided not only into bigger or smaller red heaps, but could be separated out into two distinct things—a transparent gas called oxygen and a liquid known as mercury. It was found out, too, that the liquid, water, could be divided not only into drops, and into oceans, but could be pulled apart into two gases—oxygen and hydrogen. In fact, there were very few things that could not be divided into other quite distinct things.

Some sixty or seventy things, however, such as iron, and gold, and oxygen, could not be divided into different things: they could be arranged in bigger or smaller bits, but each bit, big or small, was alike in chemical characters. These chemically indivisible substances were called 'elements,' and it was soon found out that all the other things in the world—men and stars, and butterflies, and strawberries—were just mixtures of these few elements. There seemed good reason, too, to believe that the elements consisted of infinitely minute particles or atoms which had a particular

size, shape, and weight, and which could not be further subdivided or altered.

In the course of the chemical researches that led to the conception of such things as elements and atoms, many wonderful things were discovered. What could be more wonderful than the discovery that water consisted of two dry gases, and that two dry transparent gases could wed together and make the liquid known as water? What could be more wonderful than the discovery that gold, the hard glittering metal gold, if wedded to chlorine, became a transparent fluid, and that out of the transparent fluid, the hard glittering gold could be again recovered? What, indeed, could be more wonderful than the general discovery, afore-mentioned, that all the millions of objects in the world were made out of seventy or eighty fundamental substances? 'As all the faculties of a powerful mind can utter their voice in language whose elements are reducible to twenty-four letters, so all the forms of Nature, with all the ideas they express, are worked out from a few simple elements having a few simple properties.'

Granite and water, and lava and rubies do not seem to have much in common; but they have elements in common. As a matter of fact, the most diverse objects are often built out of exactly the same chemical substance or substances. Diamonds, carbon, and coal are, chemically speaking, the same substances: they are made of the same element, carbon; and the differences between them are due mainly to differences in the arrangement of the atoms of the carbon. Carbon, too, in

conjunction with oxygen, is found in the bubbles of gas which rise in ordinary effervescent water. Here, then, we have miracles and transformation scenes.

Amazing though these discoveries were, even more amazing was the light that chemical analysis shed upon the phenomena of life; for it was found that all living matter was composed of the same few elements—elements found quite commonly in inorganic matter. A flea, an elephant, a worm, a cabbage, a man, are mainly composed of carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus. The living substance of each is built up out of billions of particles known as 'cells,' and each cell is essentially a little packet of the aforesaid elements. The carbon is just the same substance that is contained in a diamond or a bit of coal, the hydrogen just the same element that we find in water, the oxygen and nitrogen the same gases that we breathe every moment, the sulphur the same yellow substance that we use for fumigation, and the phosphorus the same phosphorescent element that we find on the head of a match. Indeed, practically every element necessary for life is found in an ordinary lucifer match.

'A few gallons of water,' writes Oliver Wendell Holmes, 'a few pounds of carbon and lime, some cubic feet of air, an ounce or two of phosphorus, a few drams of iron, a dash of common salt, a pinch of sulphur, a grain or more of each of several hardly essential ingredients, and we have man according to Berzelius and Liebig. We have literally "weighed Hannibal," or his modern representative, and are ready to answer Juvenal's

question. The wisest brain, the fairest face, and the strongest arm, before or since Ulysses and Helen and Agamemnon, were, or are, made up of these same elements, not twenty in number, and scarcely a third of the simple substances known to the chemist. The test-tube, and the crucible, and the balance which "cavils on the ninth part of a hair" have settled that question.'

The matter may be presented more prosaically as follows. In the body of a woman of average size there is enough water to fill a nine-gallon barrel, enough oxygen to fill eight hundred nine-gallon barrels, enough carbon to make nine thousand lead pencils, enough phosphorus to make eight thousand boxes of matches, enough hydrogen to inflate a balloon capable of lifting her to the top of Snowdon, enough iron to make five tacks, enough salt to fill six ordinary salt-cellars, and four or five pounds of nitrogen.

Had carbon, or lime, or iron, or hydrogen, or phosphorus been omitted from the crust of the world, there had been neither man, nor mouse, nor microbe.

The most elementary living organisms, the so-called unicellular organisms, such as amœbæ and yeast, consist of single microscopic packages of the atoms we have mentioned; while the higher organisms consist of millions of such packages built up together as a house is built of bricks.

The little packages of atoms which are the basis of life are known as cells, and their contents are known as 'protoplasm.'

Chemists have analysed cells very carefully, and have discovered that they contain thousands of

atoms clustered together into groups known as molecules. Compared with the chemical combinations that we find in non-living substances, cells are amazingly complex. A molecule of water consists of two atoms of hydrogen joined to one of oxygen; a molecule of sulphuric acid consists of two atoms of hydrogen, one of sulphur, and four of oxygen; whereas a single molecule of 'protoplasm,' as the living matter is called, contains some thousands of atoms.

The number of atoms and molecules in a tiny cell is surprising. The liver is made up of thousands of microscopic cells, yet each cell contains about 300,000,000,000,000 atoms grouped together in 64,000,000,000 molecules; while the human ovum, which is smaller than the dot on an i, has been calculated to contain 8,640,000,000,000,000,000 atoms combined together into 1,728,000,000,000,000 molecules.

If the protoplasm is to live it requires also to be saturated with water resembling dilute sea water. Indeed, most protoplasm is found to contain about 80 per cent. of water.

So much for the chemistry of the cell. Let us look now at its shape and microscopical characteristics. A cell may be round, or branched, or elongated. The cells of the liver are round, the cells of the brain are branched, the white cells that float in the blood are branched, the muscle cells are elongated.

Seeing how minute most cells are, one would be inclined to think that they cannot have any structure; but they have a very distinct structure, and distinguishable parts. Round each cell is a

cell-wall, and in the centre of the cell is a nodular core called the nucleus.

The cell-substance within the nucleus, and the cell-substance outside the nucleus, within the cell-wall, can be stained, when both are found to be made up of the networks with granular, or jelly-like, material in the meshes of the nets. The cell, therefore, is not simply a packet of jumbled-up molecules; it has a definite structure. The molecules of the protoplasm are arranged so that there are parts within parts. Nothing like this is ever found in inorganic chemical combinations. The way in which crystals are built up, atom by atom, molecule by molecule, is very wonderful, but crystals are homogeneous and show no differentiation into parts.

But the most extraordinary thing about cells is their power of movement, of assimilation, of reproduction, and of respiration. Here, again, we meet with chemical processes which are not seen in dead matter. The molecules of the cell are continually breaking down and being built up again, and during the period of growth, the building-up process is more active than the breaking-down process. The most surprising part of this surprising phenomenon is that the molecules of the living cell have the power of repairing their own substance, and of building up new molecules out of what are known as food substances which come to the cell, not in the shape of ready-made protoplasm, but in the shape of fragmentary material. Thus, the cell has the power of taking the carbon of sugar, and the carbon and hydrogen of fat, and building them

up, together with nitrogen from quite different sources, into the complicated nitrogenous substance of life—the so-called 'protoplasm.'

Respiration, which may be briefly defined as the annexation of oxygen in the form of gas, and the surrender of carbon-dioxide in the form of gas, always takes place in living cells, and is closely connected with the phenomena of assimilation and the phenomena of movement.

But the chemico-physical processes whereby cells assimilate food, and the chemico-physical processes which result in movement, are very complicated, and only very partially understood. They are part of the mystery of life.

All cells not only assimilate and respire, but also reproduce themselves by a process of division. A cell will grow for a certain time, to a certain size, and then it will get a waist, and divide into two; and, provided that there is enough food material to make living protoplasm, the process of reduplication may go on indefinitely.

Some cells, when they divide, separate from each other and lead separate existences, and are known as unicellular organisms; while other cells, such as the ova of the higher animals, or the seeds of trees, divide without separating and become built up into multicellular organisms. In such cases, a great variety of cells, *e.g.* nerve-cells, muscle-cells, liver-cells, may be produced. The rapidity with which cells multiply in this way is amazing. The cholera bacillus, for instance, can divide into two every twenty minutes. At this rate, one cholera bacillus might in one day become 5,000,000,000,000,000,000,000, with a weight of about

7366 tons, and in a few days might grow to a mass as big as the moon. Pasteur once declared that he could cover a surface of wine, equal in extent to the floor of the hall in which he was speaking, with the *Mycoderma aceti*, in the space of twenty-four hours, simply by sowing minute specks here and there; and Punnett bred in a year sixty-seven generations of rotifers averaging thirty a generation, and calculated that if he had been able to rear all the animals, he would have had 'a solid sphere of organic matter greater than the probable limits of the *known universe*.'

In the case of unicellular organisms, there seems no end to reduplication. For hundreds of thousands of years life has been on the earth, and all the unicellular organisms now known are progeny of the divisions of the original cells. Billions and billions of cells must have been formed, and there is no reason to doubt that the process may go on for hundreds of thousands of years yet. A material with such power of unending self-propagation seems in a sense immortal, and a great German scientist speaks of 'the *immortality* of the germ-plasm.' Further, an American scientist, Alexis Carrel, has lately shown that even after one of the higher multicellular organisms is dead, the cells of his body may be kept living, and may be induced to multiply indefinitely if preserved in suitable nutrient solutions.

In the case of the higher multicellular organisms, division seems to stop when the organism is full-grown, or at least soon after the change called death; but it does not really necessarily stop, for male and female give rise in life to little individual

cells which, under certain circumstances, join in couples, and thereafter proceed to divide again and again, and this alternation of multicellular growth and unicellular recommencements seems eternal. Further, there are in the body thousands of little free cells that swim about in the blood, and that wander about in the looser tissues of the body, and these seem to continue multiplying up to the very time of death.

We have said that in the centre of each cell is a nucleus containing a network of fibres. This network is easily stained, and so can be easily watched under a microscope, and it has been found to behave in a most extraordinary manner during the process of cell division. Before the cell divides, the branched network of fibres separates into a number of simple rods or loops, and each rod or loop splits into two. After this splitting, half the rods or loops go to one pole of the cell, and part to the other, and when the constriction of the cell takes place, half are therefore included in one daughter cell, and the other half in the other. In each species of animals one specific number, and always the same number of rods or loops appears, and however often the cell divides this same division of the rods or loops between the two halves is contrived. The unravelling of the network, the splitting of its pieces, the rearrangement of them into two new nuclei, and the formation from them thereafter of a branching network, is surely a very extraordinary phenomena. We cannot explain it; we cannot understand it; and though attempts have been made to construct cells and produce such phenomena by known physical

processes, no one can say that the attempts have been successful. It is a process evidently of the greatest delicacy, working with the greatest arithmetical and technical accuracy, and evidently essential to the multiplication of cells. One result certainly seems to be that the specific character of the cells is maintained in millions and millions of successive duplications.

If a motor-car were of itself to divide into two motor-cars, it would not be more extraordinary than the division of a cell. Yet everywhere, all over the world, from all time, such division is perpetually taking place; sometimes resulting in millions of unicellular animals such as amœbæ, sometimes resulting in such marvellous compound organisms as trees, and flowers, and birds, and men.

In the higher organisms, as we have already said, new cycles of development are usually initiated by the conjunction of two cells, one derived from a male, and the other from a female organism. In the case of animals, the cell derived from the male is called a 'sperm,' the cell derived from the female an 'ovum,' and the process of conjunction is known as fertilisation.

The sperm and the ovum each contains in its nucleus the number of loops characteristic of its species, and therefore one might think that when sperm and germ join together the number of loops must be doubled; but before sperm and germ unite and become incorporate each divides in such a way as to get rid of half of its loops, so that conjunction does not double the number of loops but merely restores the original typical number. This, again, is a most extraordinary

thing which cannot be explained, and which cannot be considered as an ordinary chemical phenomenon: it is a phenomenon more comparable to the operations of voluntary muscles. We do not know how it is done: we do not know why it is done.

Altogether, the phenomena of cells—little microscopic dots in most cases, be it remembered—are very amazing.

Think of it! We put three little packets, each about the size of a pin-head, each containing atoms of carbon, hydrogen, oxygen, and nitrogen, into the ground, and now one becomes a lily, and one a violet, and one a wall-flower. Each little jumble of molecules does what a living man never could do: it collects elements of hydrogen, and oxygen, and nitrogen, and sulphur from the air and soil, and makes leaves, and petals, and roots, and seeds, with the same capacity of growth. No mistake is ever made: each seed contains the same substances, in about the same proportions: each seed has apparently no parts, and yet each grows into a perfect specific flower. There are about a million seeds of a million different flowers, and each has power of growth, and each grows into its own flower. It is an amazing thing!

Not less amazing are the seeds of animals, which, in like manner, are just little packets of atoms, and, in like manner, collect other atoms, and become perfect animals each after its kind.

We are so accustomed to such miracles that they seem to us commonplaces, and so we miss the refreshment and inspiration of the wonder of life. We forget that 'if He thunder by law, the

thunder is yet His voice,' and so life is divested of much of its divine significance.

Let us realise that these little packets of atoms we know as seeds and ovums are thaumaturgists, and work miracles that should be breath-taking marvels to us as long as we live.

The most wonderful of all things is man, and the fertilised ovum that grows into a man is the most wonderful microcosm in the universe: it not only grows into a man, but it grows into a man resembling his parents, and often resembling them not only in general characters but in minute details.

Let us look for a moment at this wonderful little packet of atoms. The little packet, or 'cell' as it is usually called, is very minute. It is smaller in size than the full stops upon this page, yet it contains, as we shall see afterwards, representatives of every part of man. The babe is, of course, built up of atoms brought to the ovum from the mother's blood; but the building up of the limbs, and organs, and tissues of the child is known to depend on particles already in the cell before its growth begins. The mother's blood plays only a passive part in the development of the child: it is the little speck itself that decides what it is to become. So far as the microscope can detect, there is no difference between the ovum of man and the ovum of other mammalian animals. They are all about the same size, and they all look almost exactly alike. 'Even when we use the most powerful microscope with its highest power,' says Haeckel, 'we can detect no material difference between the ova of man,

the ape, the dog, and so on.' Chemically, too, there is no appreciable difference: each consists of a little packet of carbon, hydrogen, nitrogen, oxygen, and sulphur atoms.

Even after it begins to grow, the human ovum has no very characteristic human feature: up to the end of the first month, there are 'no features by which the human embryo materially differs from that of the hare, the ox, or the horse—in a word, of any other higher mammal. It is not, indeed, till the last four months of fœtal life that the human embryo becomes unmistakable.'

And yet one tiny microscopic cell will grow a man, and another microscopic cell a greyhound, and another microscopic cell a monkey; nor does any cell ever mistake its way. It does not explain the matter or make it any less wonderful to say that it is only a question of heredity. It still remains a most marvellous thing that a little cell can become a man and reproduce, with absolute accuracy, all the characteristics of a man.

The development of the human ovum is a matter primarily of division, and each cell before dividing goes through the preliminaries we have mentioned.

The human embryo, like the embryo of all mammals, passes through certain stages, and it is commonly supposed that the stages represent steps in the evolutionary progress of the organisms. Thus, the cell is supposed to represent the unicellular organism in which all life began, and the double-walled structure which soon appears is supposed to represent the polyp-like creature which in time was evolved from the

original unicellular organism. And even beyond this point the embryo is believed to record its ancestral history. According to Haeckel, indeed, man is a patchwork made up of relics of various animal ancestors. He has inherited his intestine from polyps, his nervous and muscular system from flat worms, his vascular system, body-cavity and blood from true worms, his chorda and branchial gut from creatures like sea-squirts, the articulation of his body from lancelet-like fishes; his skull and higher sense organs from fishes like lampreys and hag fishes, his limbs and jaws from fishes like sharks, his five-toed foot from amphibians, his palate from reptiles, his hairy coat, mammary glands, and external sexual organs from primitive animals.

According to theory, all this patchwork has been put together by the selective influence of environment; the five-toed foot, the hairy coat, and the mammary gland, and other ancestral inheritances have survived, because useful, in the struggle for survival; but relics of other characters (such as the appendix, and such as the third inner eyelid of the shark) have been kept whose use is certainly not apparent.

Other ancestral characters, too, that are now worse than useless sometimes appear. At one stage of its existence, for instance, the embryo has four grooves in its neck, and an arrangement of blood-vessels representing gills, and the gills covered by a lid or 'operculum' such as is found in certain fishes. As development proceeds the gills are obliterated and the lid disappears, but in some individuals there remain vestiges of the gill

stage in the shape of a small pit in the neck, or of small tags of skin. Again, the double hare-lip which is found in some adults ought properly to be called a shark-lip, since it occurs normally in sharks, and is probably a relic of the shark stage through which man is supposed to have passed in his evolutionary ascent. Cleft palate, again, is a reptilian condition, and serves to record man's descent from a reptile. Other instances of unfortunate historical records might be noted. At least, this is the interpretation put upon them by orthodox science.

At one time, it was thought that a miniature man existed in the ovum, and that development was merely a matter of growth; that, in fact, Topsy's explanation of her development—that God made her so long and she growed the rest—was a right description of the process. We know now that that is not the case. There is no miniature man in the ovum, only, at most, microscopic particles representative of his various parts and organs; and these are not even arranged as they are finally arranged in the body.

We shall not attempt here to give any detailed account of the growth of the body; but day by day, week by week, development goes on, and in the end we have a man—a tremendous colony of billions of cells, most of them alive, but a few, like some of the cells of nails and hairs, practically dead. Over the surface of the body are the layers of cells known as the skin, in the jelly of the eyeball are branching cells, in the brain and spinal cord are millions more, the liver contains countless thousands of them, the muscles are simply long

modified cells, the bones are cell-products, the blood is swarming with cells, the intestines are lined with cells, and in the ovaries are these wonderful cells from which all the other cells may be born. The liver-cells secrete, the kidney-cells excrete, the muscle-cells contract, the brain-cells think, the red blood cells carry oxygen, the white blood cells eat up microbes: all the cells assimilate and keep alive, and all are so arranged in structure and function as to form a great co-operative society where each works not only for itself, but also for the whole community. The brain-cell works the muscle-cells of the big toe, five or six feet from it: the little cells in the liver store up sugar for the use of the whole body, the brain could not think were it not for the labour of the cells in the intestines, nor could the heart work were it not for the activity of the little red cells that it pumps through it sixty or seventy times a minute. Each for all, all for each: each cell is an individualist and yet a socialist, a happy combination that the whole man, as a member of human society, has not yet attained.

CHAPTER II

THE ASSEMBLING OF THE ELEMENTS OF A MAN

Man is made, as we have said, mainly of the elements carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus. The ovum from which he arises is built up of these elements, and he himself, as an adult living man, 'flesh and blood and sinews and the rest,' is nothing but a conglomeration of them. The most wonderful parts of him; his brain-cells, his liver-cells, his retina, his muscles, his nerves, are merely these few elements cunningly compounded.

But where did these elements come from, and how are they built up into organic living tissues? Originally they were in a nebula. The elements in my cerebrum, every atom of them, once blazed and seethed and surged in the nebula, at a temperature of thousands of degrees Fahrenheit. Then the spinning sun in some way divided into the molten masses known as the Sun, and Mars, and Venus, and Jupiter, and the Earth, and the other planets.

At that time there was certainly no more life in the Earth than there would be in a cauldron of boiling metal. It was, in fact, just a giant cauldron of white and crimson lava lifted into white and crimson tides by the tug of the sun. What fierce, steaming, bubbling, glowing, plangent tides they

must have been, boiling with their own heat, lashed into fiery fury by heavy metallic vapours, scourged by iron hail, stabbed by perpetual lightning flashes!

In time, about fifty-six million years ago, the tidal tug of the sun tore away a fragment of the Earth, and the fragment became the moon, and soon thereafter the Earth began to solidify. Gradually the molten seas cooled down and formed a crust,—a crumpled hummocky crust, no doubt, like the broken ice of the Polar seas,—bossed with tremendous volcanoes spouting lava, and steam, and carbon-dioxide.

In the beginning was the Word, and perhaps the Word was the thunder rumbling in the hot throats of the volcanoes. For the volcanoes belched steam, and the steam condensed in time as water, without which no life can be; and the volcanoes also belched carbon-dioxide, which is the corner-stone of the temple of organic life.

In the days of its turbulent infancy the Earth probably had hundreds of thousands of volcanoes, and as they vomited out the molten metal and piled it up into mountains, they must have undermined the still unstable crust so that depressions would be formed. At first a little hot water would trickle down the volcano and would collect in a depression as a pool, but year by year the depression would deepen and the water would gather till ultimately great oceans of warm water would be formed.

The volcanoes, then, supplied plenty of water, and plenty of carbon-dioxide, and, no doubt, plenty of sulphur too; but we still require nitrogen,

oxygen, and hydrogen before we have all the elements requisite for living tissue. Where did they come from? Nitrogen is a very inert unsociable gas unwilling to wed with other elements, and it was probably left over when the other elements of the crust joined together to form basalt, and granite, and the other igneous rocks; while plenty of oxygen and hydrogen would be formed by the decomposition of the steam into oxygen and hydrogen by the excessive heat of the early crust. Many thinkers have supposed that there was no oxygen till it was produced by the vital chemistry of green plants; but we do not see the necessity for such an hypothesis.

Thus then the metallurgical processes of the molten world would result in a plentiful supply of carbon-dioxide, nitrogen, hydrogen, oxygen, and water.

In the rock of the crust, and in the mud of the ocean-bed, there would be also plenty of sulphur and phosphorus.

But the mere assembling of the materials of life will not make living things. How were these elements, fortunately or providentially ready at hand, compounded? We see various compounds formed every day under suitable circumstances. For instance, by passing a spark through hydrogen and oxygen we can make them combine into water. Under what circumstances, in what way did the lifeless elements—carbon, hydrogen, oxygen, nitrogen, and sulphur—join together into living tissues? We never see such conjunction nowadays. No man has ever seen these dead elements conjoin into a living creature.

About a thousand different atoms enter into the compound protoplasm; but we cannot believe that if chemical ingenuity brought dead atoms together in exactly the right proportion they would become alive. In sore travail was life brought forth; it required more than a chemist with a test-tube and a crucible to produce life: it required a burning sun, and a molten world, and lightning-smitten volcanoes. Just consider what the chemical synthesis of life, even in the lowest form, would mean. Suppose that a great chemist brought together the necessary atoms, and by heat and electricity made them combine into, say, a little amœba—a little mass of jelly-like protoplasm squirming about in the microscope field. That might not seem to mean very much: all the motions might be explained by alterations in surface-tension, and osmosis, and so on. But mark this, if that little squirming piece of jelly be alive, it is immortal: it has power to add other items to itself: it has power of dividing and giving rise to millions of progeny, and, if the Darwinian theory of evolution be true, it is capable of producing variations which, under the selective influence of environment, may some day grow a man: in its little loins are crocodiles, and elephants, and butterflies, and larks, Shakespeares, and Raphaels. We know something of energy, and something of the transformation of one form of energy into another; but I, personally, cannot believe that the atomic energy of the dead atoms, plus any form of thermal or electric energy the chemist can add to them, can ever give any conjunction of them such amazing and eternal consequences. Personally, I believe that the making of man began with the making of

the fire-mist, and that by no shorter route could a man or even an amœba be made. All the hurtlings and clashings, all the thunder and lightning, all the seething, molten seas of the primitive world were necessary to create life. There is something more behind life than any form of energy that we know nowadays—there is some force different in kind, and different in degree.

Steps in the process of creation we may guess. It seems quite likely that a cyanogen-like compound, a combination of hydrogen and carbon (which would be two of the first elements formed from the electrons of the fire-mist), formed in the sun, and was endowed there with energy of such a kind—of such a pre-ordained teleological kind—that when the earth cooled down it gripped to itself in particular ways atoms of oxygen, nitrogen, and sulphur, and formed a compound of molecules capable of going through the amazing cycle of life.

What form the first life took it is impossible to say. We know forms of life that exist at temperatures over boiling-point, and there may have been some forms of organisms able to endure much greater heat. To me it seems, *a priori*, likely that there were many different organisms, some high, some low, formed independently, and these gave rise to new spore-bearing and ovum-bearing organisms which were the ancestors of various species of living things. I think, as I have explained elsewhere (*Evolution, Heredity, and Vitalism*), it is quite as easy and quite as scientific to believe, for instance, that radiolarians, and molluscs, and fishes, and birds, and monkeys, and men arose at separate times from separate organisms—eggless organisms

in no-wise resembling their progeny—as to believe that radiolarians, and molluscs, and fishes, and birds, and monkeys, and men arose from one original germ by the effect of environment on its millions of variations. The similarity of plan on which various species are constructed is quite as well explained by a similarity in their origin, as by any hypothesis of serial ancestry and heredity; and it is little more necessary to assume genetic relationship between the flipper of a whale and the hand of a man, than to assume genetic relationship between the eye of an octopus and the eye of a man. Indeed, the Darwinian hypothesis with regard to the line of evolution and the machinery of evolution cannot now be held, and it is necessary to look for a process achieving its ends by much more direct and prescient and purposeful methods. But to this subject we must return in a later chapter.

The origin of organisms we do not know, but we do know the materials of which they are made, and we do know that organisms, from the egg up, grow and multiply by the assimilation of more such materials.

We start, then, with germ-plasm of whose origin we know nothing, a proteid substance structurally and chemically complex, and we find that it assimilates and grows.

What do we know of this assimilation?

This much we know, that even in this building we have to call in the energy of the sun, or the energy rather of some of its waves. The energy that made the germ-plasm I believe to have been the primitive sun, and the energy that enables the germ-plasm to fulfil its destiny to grow into more

germ-plasm, to grow into a man, or an elephant, is still the energy of the sun. The ancient Egyptians used to entitle their king Sa Ra, Son of the Sun, but we are all in very truth sons of the Sun.

All the carbon man adds to his body and germ-plasm is obtained ultimately from starch. He may get it from beef or mutton, but the beef or mutton is made from the starch of the vegetable food consumed by the oxen or sheep. Whatever meat he eats it has always at some point in time originated in starch, and starch is always made in green plants by the work of the sun. Wherever we see green pastures, there we know that the sun is hard at work making men and animals. The sun begins the making of man in the fire-mist, but he continues the manufacture in the green meadows.

The manufacture of starch by the sun is one of the most extraordinary things in an extraordinary universe.

The volcanoes, as we have seen, belched out at the beginning of the world great quantities of carbon-dioxide, a gas consisting of one atom of carbon and two atoms of oxygen and represented by the chemical sign CO_2, and this gas is the corner-stone of living things. There is something like three parts in ten thousand of this gas in the atmosphere, but it is not utilisable as it occurs there: we breathe it constantly, yet none we inspire will ever go to build up our tissues. We often drink it, too, in aerated waters, but we cannot utilise the carbon in this form for building purposes. Only when it is in the form of starch or sugar is carbon of any building value, and only in green plants is it found in such forms. How does the

starch come to be in the plants? As is well known, the carbon-dioxide is decomposed into carbon and oxygen, the oxygen is discharged and the carbon is built up into starch or sugar by combining it with water. But it is not such an easy thing to tear carbon and oxygen apart: they are fond of each other and cling together. One can separate the carbon and the oxygen in carbon-dioxide by burning a wire of magnesium in a jar of the gas. The magnesium tears the oxygen from the carbon, but such force is required that there is a crackling sound as of little explosions and the carbon is flung against the side of the jar. Yet in a green lily leaf, in a blade of grass, the same disruption goes quickly and quietly on. How is it done?

In the first place, the green leaves are ingeniously constructed to bring as much carbon-dioxide as possible into contact with the green colouring matter of the leaf. The cells in the interior of the leaf are so arranged as to form a kind of spongy tissue, and the epidermis or skin on the lower side of the leaf has little openings or mouths leading into the cavities in the middle. The mouths are usually on the lower side of the leaf, so that they may not get clogged up with dust or soot; and there may be millions on a single leaf. Through these mouths the air containing carbonic acid gains access to the interior of the leaf and is brought into intimate association with the green matter or 'chlorophyll.'

This green matter, or *chlorophyll*, plays a very important part in the manufacture of starch. Only leaves containing chlorophyll can form starch.

But the green leaves and the chlorophyll granules

are merely the workshop and the bench: the real workman is the sun. All the time when the sun is shining, his waves beating across space at the rate of 190,000 miles a second for 930,000,000 miles, work quietly away at the disruption of the carbon-dioxide and the manufacture of starch. The waves that do the work are chiefly red, orange, and yellow waves of light, but the moment they reach the chlorophyll they are light no longer: they are transformed in some way into chemical force which tears the carbon from the oxygen, leaving both in a state of tension capable of work. The carbon thereupon joins with water to make starch, and the oxygen flies away ready to play its part in any combustion it may find to hand. We do not pretend to understand exactly how the energy of the sun is transformed into the potential chemical energy of the free carbon and oxygen; but transformations of energy do constantly occur, and this is one of the most wonderful transformations in nature. The starch is solid sunlight; in it, in chemical form, is the energy of the waves of light.

Let sunlight fall for only a few seconds on a green leaf and oxygen is given off, and within five minutes starch can be detected. The starch, without further assistance from the sun, can add water to itself, and make cellulose or sugar; and the sugar, without further assistance from the sun, can form proteid by chemical reaction with ammonia.

As the great Russian botanist Timiriazeff puts it: 'We possess in the sunlight a motive power; in the plant a machine in which the motive power is applied; in the carbonic acid, a raw material; in the organic matter of the plant, a manufactured

product.' And let it be added, in the manufactured product, the energy of the sun.

In green leaves the sun finds a very extensive workshop for the materialisation of his energy; for the leaves of plants present a tremendous surface to his rays. An acre covered with clover represents twenty-six acres of leaf, and an acre of lucerne eighty-five acres of leaf. So that altogether, all over the world, countless tons of starch are manufactured ready to be converted into the bodies and the energies of animals.

Such, then, is the ultimate source of the carbon of our bodies, and in many cases of the nitrogen too. We do not know exactly how carbon and water are built up into starch; but chemists say that probably hydrogen peroxide (the fluid used by ladies to bleach their hair) and formaldehyde (an antiseptic and poison) are first formed, and that the formaldehyde is elaborated into starch.

The carbon, therefore, of our bodies has an extraordinary chequered career: it is belched forth by volcanoes; it is collected in little green grottos in green leaves; and it is built up by sunlight, through the mediation of chlorophyll, into starch out of a most irritating and deadly poison. Verily our bodies require some making.

Starch consists of carbon, and hydrogen, and oxygen; but flesh or protoplasm is made of carbon, hydrogen, oxygen, nitrogen, and sulphur. Where does the nitrogen come from? Like carbon it comes from the air via green plants. Fortunately there are tons and tons of nitrogen in the air. But green plants cannot use the pure atmospheric nitrogen. Before they can use it for building

purposes it must be presented to them in the form of nitric acid, or nitrates, or ammonia. Now all these substances owe their existence to lightning which, as it flashes through the nitrogen of the air, converts that gas into nitric acid. The nitric acid is brought to the soil by the rain, and is there converted by salts in the soil into nitrates, such as saltpetre, which the plant absorbs in solution and uses to make the nitrogenous product called vegetable proteid, from which all animals ultimately derive the nitrogen that goes to the making of their bodies. The work of the root of a plant, whereby it obtains from the soil the necessary water and nitrogen for the formation of tissue, is very wonderful; but we are not able to go into it here. One little statistical fact, however, may be mentioned to show the amazing trouble Nature takes to get the material for a living man. A German scientist measured the length of the roots and rootlets and root hairs of a single stalk of wheat, and found that they measured no less than twelve and a half miles. Twelve and a half miles of root to make a few ears of wheat, a teaspoonful or two of starch and proteid! How many miles, I wonder, to the making of a man! How many miles, I wonder, to supply the energy that moved the pen of a Shakespeare!

Man, it may be mentioned, has now begun to assist Nature to make nitrates for plants by making nitrates, after her example, by sending a strong electric flash, or artificial lightning, through the air. And in order to get the power to make the spark he is now preparing waterfalls. So that waterfall power is now assisting to make the

tissues of plants and animals. A few plants, such as peas, and beans, and other leguminous plants, are able to get nitrogen from the air, in the interspaces of the soil, through the agency of certain bacteria which grow in nodules on their roots; but no one has yet explained how exactly this is effected. But these are exceptions, not the rule: the rule is that plants can assimilate nitrogen and weave it into proteid only after it has been converted into nitrates.

As in the case of the formation of starch from carbon, so in the case of the formation of nitrogenous or proteid substances, we know little of the processes involved. The energy necessary is supplied by the energy of the sun in the previously formed starch, and the proteid matter is probably built up of simpler nitrogenous substances, such as amino-acids. Emil Fischer, a great German chemist, has been at work for years, breaking various proteids into bits and then putting them together again, and he has succeeded in compounding amino-acids into nitrogenous substances called peptides, or polypeptides, which are on the way to proteids.

The sulphur, phosphorus, calcium, potassium, iron and other substances which are found in the proteids of the body or in the fluids bathing the proteid tissues, are obtained either directly from the soil through water, or from the soil by the mediation of the plant which absorbs them.

The fats of the body which contain no nitrogen, are made by the energy of starch out of starch or out of sugar by chemical processes that are not quite understood.

Such then, briefly, are the ultimate sources of the elements found in the human body. They come by round-about routes and are gathered, and compounded, and prepared for use by volcanoes, and lightning, and sunlight, and roots, and green leaves.

CHAPTER III

THE SKIN

'Thinke in how poore a prison thou didst lie
After enabled but to suck and crie!
Thinke that when grown to most 'twas a poore Inne
A Province packed up in two yards of skinne.'

The body, as we have seen, is made up of little pieces of protoplasm known as 'cells.' Over the surfaces of the body, the cells are united together to form skin and mucous membranes—the so-called *epithelial* tissues.

The epithelial tissues, though comparatively simple structures, are really very wonderful. Think how delicate and pliable the skin is, and yet how durable! Though soft as silk it yet resists an enormous amount of wear and tear. Gloves on our hands, socks on our feet, even thick boots soon wear out, but our living skin, under ordinary circumstances, practically never wears out, and in parts where it is exposed to much friction it grows thicker not thinner, so that on the soles of the feet and the palms of the hands, it may be as much as an inch thick.

When we examine the skin microscopically we find that its outer layer, the so-called *epidermis*, consists of layers of horny scale-like cells, and that under these are layers of softer and more cubical cells. The cells of the outer layers of the skin have been compared to dry raisins as packed in a

box, and the lower ones to grapes packed tightly. No blood-vessels and no nerves run among these cells, and they therefore do not bleed when cut, and have no sensation. Under them, however, and jutting into them, are numerous nerves and blood-vessels, bound together by a string material known as *fibrous tissue,* and forming together a layer known as the *dermis* or true skin, which is the seat of sensation. It is true that the very surface of the skin seems to have sensation; but the sensation is really in the lower layer; and when the skin is blistered so that the superficial layer is separated by fluid from the lower layer, we can cut the superficial layer without causing any pain. Indeed, the outer dry horny cells of the skin may be considered dead, and we may be said to be encased in corpses. A good thing, too, it is, that we are so encased, for if it were not for these dead and moribund cells, the unprotected nerves would be too sensitive to impressions, as we well see when the epidermal layer happens to be removed.

How does it happen that the surface of the skin lasts so well? It lasts just as the front ranks of soldiers in battle last; simply because as quickly as one is knocked out another steps in from behind, and takes its place. The superficial horny cells are continually rubbed off, but the rounder cells of below become flatter, and harder, and more horny, and step into the breach. As long as we live, the cells just below the surface layer of the skin are multiplying. In the course of a long life, the number of skin cells formed must amount to a very considerable heap; and it is strange to think

that underneath the placid surface of the skin the cells are seething in a turmoil of birth.

There are no blood-vessels, we have said, in the superficial cells; but, of course, the cells have to obtain food, and they obtain it from the blood-vessels in the lower layer of the skin. The epidermal cells, in fact, may almost be considered as sown and grown on a nutrient material, and if a few such cells be planted on a raw surface denuded of skin, they will grow and form a skin over it, much as mould does if it be sown on the surface of a jar of jam.

The colour of the skin depends chiefly on pigment granules in the deeper cells of the epidermis. When there is abundance of dark pigment the skin appears dark, and may be even negroid in character. When pigment is entirely lacking, we have an albinoid condition.

Over the greater extent of the human skin are hairs, and when we examine these, we find that they are composed of horny epidermal cells arranged in the form of a tube, with a core of softer cells. Nails are also formed of the horny cells of the skin.

The skin owes its function of sensation to the nerves in its lowest layer. In this lowest layer (the dermis) where the skin is most sensitive, the nerves end in peculiar bulbous enlargements known as 'tactile corpuscles,' 'end bulbs,' or 'Pacinian corpuscles.'

It is popularly supposed that the skin feels heat, and cold, and pressure about equally over any particular area; but, really, there are separate nerves in the skin which perceive heat, and cold, and pressure;

and one part of the skin may be specially sensitive to one impression, and another part specially sensitive to another impression. One may map out the skin, for instance, into little patches—some specially sensitive to cold, and some specially sensitive to heat. Or one may map out the skin according to sensitiveness to pressure; and in this respect, it will be found that the forehead and the back of hand and forearm are more than twice as sensitive as the finger.

Discrimination of separate points is another sense-faculty of the skin, and this discrimination is finest at the tip of the tongue and the tip of the fingers. The tongue can distinguish the points of a compass as *two* points, when they are only $\frac{1}{25}$th inch apart; whereas, at the middle of the back, two points cannot be felt as two unless $2\frac{1}{2}$ inches apart.

An interesting demonstration of the varying degree of discrimination of the skin may be given by drawing the points of a compass from the wrist across the palm and along a finger to the finger-tip. If the points are about a quarter of an inch apart, they will be felt at first as one point, and the points will seem to diverge as the compass is drawn towards the tip of the finger.

The sensation of pain is probably due to special nerves, and if these nerves were paralysed or destroyed it would be possible to dip the hand into boiling water, or to hold it in a flame, without any sensation of pain. Probably, too, there are great differences in individual capacity for pain, and there is a good deal of truth in the saying that—

> 'Nature's stamp of merit
> Is capacity for pain.'

The skin and the brain are developed from the same primitive layer of cells, and, in the skin end, thousands of little nerve fibres that run between it and the brain. Were the whole skin insensitive, we would have much less sense of being and of well-being, and it has always seemed to the writer that one of the reasons why civilised nations approve of clothes is that the contact of the clothes with the sensitive skin develops one's sense of personality and individuality. The man feels *himself* when he feels his clothes. There can be little doubt that a dull skin and a dull brain often go together, and that, as a rule, a 'thick-skinned' person has literally a thick skin, and that, as a rule, the cleverest, most active, and most imaginative brains have most sense of pain. Further, provided that the pain is not too severe, it may be said that those who feel pain most usually heal most readily, since the trophic nerves and the sensory nerves are naturally developed *pari passu*.

We have spoken of the skin, so far, as a protective covering, and as a sense organ; but it has several other functions: it *excretes;* it *regulates* the temperature; it protects the tissues from the actinic rays of the sun; it *breathes* and regulates breathing. Let us now glance for a moment at those functions.

Excretion.—If we look at the skin through a magnifying-glass we see it is dotted with little apertures, and the apertures are the mouths of sweat-glands. Each aperture leads to a tube which goes with a corkscrew twist down through the epidermal layer of cells for about a quarter of an inch, and ends in the dermis in a number of loops

and coils compacted into a little bunch. There may be as many as two or three thousand sweat-glands to a square inch of skin—over 3500 have been calculated on a square inch of skin from the palm of the hand—and the total number of sweat-glands has been reckoned to be about 2½ million, representing a total length of tubing of twenty to thirty miles—long enough to reach half-way from London to Brighton!

A system so extensive must have great physiological importance. What is the meaning of this tremendous excretory apparatus?

The object of these tubes is to extract some fluid material from fine blood-vessels which surround them, and the little bunch of coils facilitates this extraction. On the average, two or three pints of fluid are excreted by the sweat-glands every twenty-four hours; but, in the case of a man working hard in hot weather, some quarts may be excreted. Workmen employed in making-up fires in a gas-works were found sometimes to excrete three-and-a-half pints of sweat in forty-five minutes, and as much as five pints in seventy minutes. When we examine the fluid, we find it to be water with just a trace of salt. Under exceptional conditions it may contain poisons, but under normal conditions it contains only water and salt. It would seem at first sight an extraordinary thing that there should be all this elaborate apparatus—about thirty miles of tubing with orifices representing an area of ten thousand square feet, just to remove a few pints of water through the skin; but when we look more into the matter it is not so very extraordinary. After all, water is a very important constituent of

the tissues; it forms, for instance, 80 per cent. of nervous tissue, 83 per cent. of the lungs, 87 per cent. of the pancreas, 92 per cent. of the retina, and enters into the composition even of the bones and of the enamel of the teeth. By the fluid of the blood, moreover, food, and gases, and waste material are conveyed to the cells of the body. Man may live for weeks without food, but a few days without water is fatal. There is nothing, therefore, so extraordinary in this elaborate provision for a flow of water through the tissues. Further, the water, as we shall see later, is of great importance in modifying the heat of the body, and is usually poured out most abundantly when the heat is greatest.

The skin contains besides sweat-glands, glands known as sebaceous glands which secrete an oily substance called 'sebum.' These sebaceous glands are usually placed at the roots of hairs and usually open into the hair sac, and the oily substance they secrete serves to lubricate the skin and keep it soft and pliable.

Even apart from the glands, the skin is an excretory organ. The dead cells constantly cast off carry with them, no doubt, many excretory products; and many poisons in the system are excreted in this way, as well as by the glands. Thus we find gouty eczema, which is probably an effort of Nature to throw off the poison through and with the skin. Thus, too, we find eruptions of the skin in smallpox, scarlet-fever, typhus, typhoid, and many other infectious diseases.

Regulation of temperature.—As we know, the body when alive is constantly hot, and maintains generally a temperature of about 98·4° Fahrenheit.

Yet heat is constantly passing away from it through the skin. It is evident at once, that the conductivity of the skin must have much to do with the regulation of this passage of heat. If the skin be a good conductor, heat will pass rapidly away; if a poor conductor, slowly; and it is quite possible—though this is a matter quite ignored by physiologists—that there may be great individual differences in this respect.

The conductivity of the skin may be increased by covering it with some substance more conductive than itself. It is largely in this manner, probably, that tight boots and gloves cause cold feet and hands. It is possible even to kill a man by accelerating the conduction of heat through his skin, and a dramatic instance of this once occurred. In a procession to celebrate Pope Leo the Tenth's ascension of the papal throne, a child was covered all over with gold leaf to represent the Golden Age, and within six hours the child was dead. Rabbits are easily killed in the same way by varnishing their skins. It is often said that death in such cases is due to interference with the excretory action of the skin; but if a varnished rabbit be kept warm by clothing it in cotton-wool, it will survive; and there can be no doubt that death is caused chiefly through undue abstraction of heat.

Even as heat-conduction through the skin can be accelerated by covering the skin with good conductors of heat, so it may be decreased by covering the skin with bad conductors, a method we employ daily when we put on our clothes.

It is possible that Nature may to some degrees alter the conductivity of the skin, so that a man

may have less conductive skin in winter than in summer, even as some animals turn white in winter with like consequences; but not in this way chiefly does Nature regulate the flow of heat.

Most of the heat of the body is formed in the muscles and the liver; and it is carried through the body by the blood-vessels as by a system of hot-water pipes, and it is from the blood-vessels in the skin that the heat chiefly radiates away. By means of the nerves in the skin these blood-vessels are regulated in such a way that the blood supply to the skin is increased in hot weather and decreased in cold. We can see how in hot weather the skin is flushed and the veins turgid; and how cold makes the skin pale and pinched. These changes are compensatory, so that there may be much exposure of the warm blood in the one case, and much protection in the other. It is a mistake, therefore, to think that a cold skin is dangerous: a cold skin simply means that the blood has retreated from the cold in order that the bodily heat may be conserved. The danger really is if the skin be full of warm blood in spite of the cold; and this dangerous condition is sometimes brought about by indulgence in alcohol before exposure to cold; for alcohol causes the blood-vessels of the skin to dilate, and prevents the contraction of the blood-vessels when contraction is most desirable. The result, accordingly, is that the blood in the cutaneous vessels gets cooled down and is carried to the internal organs in a chilly condition. All Arctic explorers are aware of this danger, and avoid alcohol before facing cold.

A hot room likewise will flush the skin; and it is

often thought dangerous to go from a hot room into cold air. This, however, is a mistake. In most cases there is no danger whatsoever, for the blood-vessels of the skin speedily contract in response to the cold. By this wonderful automatic arrangement the flow of heat is beautifully regulated to suit different degrees of heat and cold.

In great heat, however, the regulation is not in itself sufficient to keep the body cool; and then the sweat-glands (also under nerve direction) begin to act, and the skin is cooled still more by means of evaporation.

Any fluid in the act of evaporation abstracts heat from neighbouring bodies. If we wrap a wet cloth round the bulb of a thermometer (converting it into what is called a wet-bulb thermometer), the evaporation of the water reduces the temperature of the bulb, and the thermometer gives a lower reading than it otherwise would give. If we put water in a porous earthenware jar so that some oozes through the earthenware and evaporates, the water in the jar is kept cool; this device is often adopted in warm climates. If, again, we spray the skin with ether or some other fluid which evaporates rapidly, heat is so rapidly abstracted that the skin may actually be frozen.

In hot weather, then, the skin sweats, and the evaporation of the sweat keeps the skin cool.

In dry air, evaporation is more rapid and thus more effective in its cooling capacity; and, as is well known, dry heat is therefore much less oppressive than moist heat.

In fevered conditions when the skin fails to sweat, the temperature of the body keeps high, and

one often bathes the body to reduce the temperature.

The cooling effect of evaporation is most marvellous. It is the main means of refrigeration at very high temperatures; and, as is well known, man can endure remarkably high temperatures without much increase of his body-temperature. A famous Fire-King, called Chabert, used to enter an oven at a heat of 400° to 600° Fahrenheit, and it is quite certain that his own bodily temperature could not have been raised many degrees. Every day, too, workers at certain hot trades are obliged to work at a temperature of about 250° Fahrenheit, and yet their bodily temperature is hardly raised. Verily 'the two yards of skinne' often save us from being stewed alive.

Light Relationship of the Skin.—Sunlight, as is well known, kills germs; but it is not so well known that in excess certain rays, probably the actinic rays, are injurious to the protoplasm of animals. Almost all animals, accordingly, are taught by instinct to seek *cover* from intense sunlight. Not only so, but Nature does her best in many instances to render the skin light-proof. It is probable that the white colour assumed by various Arctic animals in winter is not only adapted to conserve the bodily heat at night (even as white sheets do), but to reflect back the fierce sunlight during the day; for it must be remembered that in Arctic regions the sunlight may be very powerful, and seems to always be particularly actinic. In man, the armour against the light takes the form of the black pigment particles already described. Hence we find that tropical races are invariably dark, and that tropical ex-

plorers are usually dark men, like Stanley. Fair people, in whom pigmentation is deficient, often form freckles in self-protection. It is probable, too,—though, so far as we know, the point has never before been mentioned—that the flushing of the skin caused by light and heat serves the extra purpose of increasing its opacity to actinic rays. It is well known that the blood is opaque to ultra-violet rays, hence in giving treatment by actinic rays it is necessary to render the skin anæmic by pressure. When, accordingly, we see a man with a red face we must remember that the ruddiness fulfils a useful purpose.

The African chameleon and the lizard, Anolis, have still more accomplished skins, for in strong light black pigment comes to the surface, and in faint light it wanders in again, so that the animal changes from black to green.

Respiration of the Skin.—Still one more function of the skin remains to be mentioned. *It breathes.* The lungs are essentially the organs of respiration, but the skin breathes too, that is to say, it absorbs oxygen and gives off carbon-dioxide. It is true, its breathing power is slight, but still not to be neglected.

And the skin not only breathes, to a considerable extent it regulates the breathing and the circulation. When a baby is born, it is usual to stimulate its respiration by stimulating the skin; and all through life the respiration and circulation remain under the influence of the skin reflexes, as we know quite well when a plunge into cold water makes us gasp for breath, or when a breeze gives fresh vigour to the heart and drives away a feeling of faintness.

To cover the skin, as is so often done, with garment after garment, is to deprive the great organic functions, both of respiration and of circulation, of some of their most useful stimuli; and those who are overclothed are rarely vigorous. Indeed, the nerves of the skin being protected from the stimuli to which they are meant to respond, forget how to do their duty if suddenly called upon to act. Thus, if a person who is warm and habitually overclad have his bare body exposed to cold air, the nerves which ought reflexly to cause contraction of the blood-vessels in the skin are unable to work efficiently and promptly, and so the person's blood, as it circulates through the cold skin, may be cooled down to a dangerous extent. People who are supposed to be delicate, and to catch cold if exposed to draughts and colds, are usually just people who protect and pamper their skins till the cutaneous nerves forget their business, and such people would become much healthier and stronger if they exposed their skin to changes of temperature—even to breezes and draughts. The skin is meant to be exposed to some extent to moving air: it is meant to be a great evaporating surface: it is meant to send constant messages to the respiratory and circulatory centres. Indeed, it has lately been demonstrated, as the writer suggested some years ago, that evil effects of impure air are due not so much to the impurity of the air as to the fact that impure air is usually still, and so fails to stimulate through the skin the circulation and respiration. If the impure air is set in motion by a fan, most of the feelings of languor, and faintness, and drowsiness disappear. The writer has often found that if

he has slept in a bed in the centre of a very large room, he has awakened next morning feeling heavy and tired, and the reason no doubt has been that the air in the centre of the room, being far away from windows, and chimneys, and doors, has been to all intents and purposes stagnant.

Moving air is essential to vigour of mind and body, and the fear of draughts and fresh air is very foolish and ill-founded, as thousands of patients in open-air sanitoria have practically proved. Draughts are harmful only if they impinge on localised areas of the skin, or if they are so cold and so long continued as actually to lower the temperature of the body, or if they contain germs, as draughts, for instance, that blow over dirty, dusty carpets usually do.

CHAPTER IV

THE BONES

'As thou knowest not the ways of the spirit nor how the bones do grow in the womb of her that is with child, even so thou knowest not the works of God who maketh all.'—SOLOMON.

'And the narrowest hinge on my hand puts to scorn all machinery.'—WALT WHITMAN.

We have seen that the living tissues of the body consist of little particles known as cells, and that each cell is a very complex machine; but it might be thought that the bones are quite simple and commonplace structures. They seem just rods, and ribs, and lumps of lime designed to support the softer structures.

But even the bones are far from simple: they are cunningly and elaborately wrought in very wonderful ways, for various complex purposes. The moment we begin to consider their real nature and origin, we find that, like other things in the world, they required for their making, the sun, and the stars, and the clouds, and the seas, and all the great natural forces.

Think for a moment what the lime of them means. Where did it come from originally? Who were the hodmen who brought it to the temple?

The lime in our bones comes from the lime in our liquid and solid food; and the lime in our liquid and solid food, whether animal or vegetable, comes ultimately from the lime in water. That is

quite certain. But how does the water happen to contain so much lime? We must go a long way back. Here is the story of it.

By forces which we only partly understand, the earth was thrown off from the blazing sun as a seething mass of molten substances and gases,—thrown off with such a force and in such a way that the action of gravitation retained it spinning in an orbit round the sun.

Under the action of gravitation, centrifugal force, and chemical affinity, the spinning, molten mass, as it cooled, separated out into various minerals and rocks and formed a crust. This crust, which is now deeply buried under sediment and lava, and whose mineral character we can only surmise (it is not impossible that it was gleaming with silver, and gold, and diamonds), was soon bossed like shagreen with active volcanoes, and it is the igneous rocks vomited by volcanoes that must be regarded as the original source of lime. But the lime we find in igneous rocks is combined with the mineral, silica, and is *locked up,* so to speak, in the form of silicates. How then was the lime extracted from the early igneous rocks, and given to vegetables and animals in a watery solution? In this wonderful way. The self-same volcanoes that vomited forth the silicates also vomited steam containing carbonic acid; and this steam and carbonic acid rotted the silicates, broke them up into their mineral elements, and formed carbonate of lime from the lime they contained. Further, the steam which had an excess of carbonic acid in it dissolved the carbonate of lime, and thus we reach water with lime in solution.

Century after century, æon after æon, the blazing volcanoes manufactured water and carbonic acid, till finally there were huge oceans with abundance of lime in solution. Verily, Vulcan worked well at the forge of life, building mountains, and making seas, and preparing lime for our bones.

In the primitive seas, there swarmed millions and millions of marine organisms that collected the carbonate of lime in the water, and built it up into shells, and when the organisms died, the shells fell to the bottom of the sea, and accumulated there for millions of years, so that tremendous quantities of lime were withdrawn from circulation. But the withdrawal was only temporary. Nature was building up a reserve fund for future use. In the so-called 'Tertiary Epoch' of the earth's history, a great part of the floor of a great ancient sea (called by geologists the Tethys Sea) rose and bulged into the air as land and mountains, carrying with it in its rise all its enormous deposits of lime. A considerable portion of Europe and Africa and Central Asia were thus upheaved from the bottom of the sea. The chalk cliffs of England, the Alps, the Pyrenees, the Himalayas, Mount Sinai, are all made of deep-sea lime.

So that when man, millions of years later, came upon the scene, there was plenty of lime-water to irrigate the land, quite apart from the lime locked up in the igneous silicates.

En passant, we may remark that to us the quantity of lime in the ancient seas, as evidenced by the deposits now on dry land, would seem to indicate that lime was more plentiful on the top of the ancient volcanoes than it is now in the

silicates that still remain intact; and the quantity of lime shown by the spectrum in the atmosphere of the sun, lends some support to this supposition.

Anyhow, we owe lime, in the first instance, to the volcanoes that built mountains of rock, and supplied steam and carbonic acid to destroy them again. And we owe lime, in the second place, to the collecting agency of minute sea animals, and to the tremendous convulsions of Nature that raised the sea floor into dry land and high mountains. Nor must the part played by the sun be forgotten. It was volcanoes that built up the first mountains, and that supplied the sea-water, but it was the sun that kept the water going and made the wheels go round. Save for the sun, the volcano steam would have just collected in depressions in the earth's crust, and the only motion of the water would have been the motion of the tides. But the sun raised the water into the sky, where it condensed into drops and clouds on the nuclei of volcanic dust, and then, pulled down by gravitation, fell as rain, and made streams and rivers. A cloud floating in the blue sky may seem a very light thing, but it may represent tons and tons of water; and to raise tons and tons of water to the top of Ben Nevis, or Mont Blanc, means prodigious lifting work. There is surely a good deal of romance about the grinding of the mills of God, and though they grind slowly, yet they grind exceeding small. Think of the steaming, roaring, flaming volcanoes! Think of the rain of shells into the ocean depths! Think of the elevation of the ocean floor into mountains like Mont Blanc! Think of the cloud floating in the sky and the torrents tearing the rocks asunder! All

these worked to get lime for the bones in the fingers that are penning these words.

But the lime made by water and carbonic acid out of the lime of rocks is carbonate of lime; and our bones are made of phosphate of lime, so that most of the rock-lime is bound up into a new combination with phosphorus before it is moulded into bone. The complicated chemical processes by which this is effected, we need not attempt to describe; but we will just mention the fact that phosphorus, like lime, is a product of ground rock, and that it is found in small quantities in all soil, and in all living matter.

We have dealt at some length with the production of the material for bone-making, because it is an interesting illustration of the unity of Nature, and because it makes a certain appeal to the imagination; but the production of the phosphate of lime that is necessary for bones is a very small part of the making of a bone.

Chemically speaking, bones consist not only of phosphate of lime, and carbonate of lime, and small quantities of a few other minerals, but also of animal matter, and further, as we said before, the structure of a bone is not simple, but very complex. If we were to take phosphate of lime, and carbonate of lime, and fluoride of lime, and phosphate of magnesium, and sodium chloride, in the right proportions, and if we were to mould them into the exact outward semblance of a bone, there would still be a world of difference between the imitation and the real bone.

A real bone is really a very wonderful and beautiful thing. Let us look first at its structure. If we cut open such a long bone as the thigh-bone, we find that

there is a central cylindrical cavity which runs along the shaft of the bone, and that this cavity is filled with bone marrow: we find that the bony matter is dense and compact like ivory all round the circumference of the shaft, but that towards the central cavity it becomes spongy in structure: and we find that both ends of the bone are made up mainly of similar spongy bone. Whatever bone we examine, we find always compact and spongy bone, and, in the case of the long bones, we find usually a central cavity.

In making the long bones hollow, Nature shows her wisdom, for she economises material, and makes the bones light and elastic without reducing their strength, for, as is well-known to engineers, a hollow cylinder, up to a certain size, is as strong in many ways as a solid rod of equal diameter. Again, the filling of the heads of the long bones and the centres of the short and flat bones with spongy material serves to diminish shock and jar when force is applied to the bones. But, further, the little beams, and spokes, and arches of bone that make up its spongy part are so disposed and so arranged as to resist the special strains to which the particular bone is disposed. In the case, for instance, of bones more or less round the spongy part of the bone, it is arranged roughly on the principle of a wheel within a wheel, with spokes and a hub; in the neck of the thigh-bone the layers of bone are arranged in decussating curves like Norman arches, in order best to sustain the weight transmitted on the head of the thigh-bone, and whatever the shape of the bone, and the special strains or shocks to which it is exposed, the spongy bony tissue is arranged accord-

ingly. This is one of the most extraordinary things about the structure of a bone, and one which art could not imitate.

The dense part of bones, too, is not merely masses of lime: it has a very elaborate structure, for it is laid down in thin parallel plates. The plates near the surface of the bone are arranged parallel with its surface. Thus, if we cut a thigh-bone in two by a cut straight through its middle, we can see with a microscope a series of parallel rings such as we see in the stem of a tree when it has been sawn across. Deeper in the dense layer of the bone, the plates are arranged round long canals that perforate the bone in different directions. Between all these parallel plates of bone, again, are found hundreds of microscopic spindle-shaped or lemon-shaped spaces.

Even if art could imitate these broad structural features of bone which we have mentioned, art would still be infinities away from real bone.

We have mentioned the phosphate and carbonate of lime, and other minerals that enter into the composition of bone, but bone is not made of mineral alone, it contains about 30 per cent. of an animal substance called 'collagen,' which on boiling is converted into gelatin. It is this substance that is extracted when we make bone soup, and it gives the bone additional tenacity and elasticity. So consistently is it distributed through a bone that if all the minerals in a bone are dissolved out by means of acids, the animal matter remains behind, and, though the bone is rendered soft and pliable, its shape is still preserved. Similarly, if all the animal matter be removed by burning a bone, the

bone becomes more fragile and brittle, but the mineral matter still maintains the shape of the bone. So that we can almost say that each bone consists of two bones—a bone made of collagen and a bone made of mineral matter.

Even in fossil bones the animal matter is often retained for long periods, and Gimbernat once made soup from a mastodon's tooth, while Dr Buckland made soup from the bones of a prehistoric hyæna.

In its natural condition, while it consists both of organic and mineral matter, bone has considerable elasticity, and if a skull be thrown upon the ground it will bounce up again, as some of us may have noticed when we come a cropper on the ice. All the long bones, it may be noticed, are curved, and this of course gives opportunity for their elasticity to come into play. The ribs are specially elastic to facilitate respiratory expansion and contraction; and Arab children make excellent bows out of the ribs of camels.

Compared with other substances bone is remarkably strong. It is twice as strong as oak and nearly three time as strong as elm or ash. The spongy bone, too, as we have already stated, is built up in such a way as to be able to resist great pressure and strain. A cubic inch of spongy bone, weighing only 54 grains, was taken from the lower end of the thigh-bone and put in the same position it occupied in the upright body, and it was found that it would support a weight of four hundred pounds without giving way in the least.

Phosphate of lime is much harder than carbonate of lime, and the large proportion of phosphate of

lime combined with animal matter in the bones renders them very hard. All animals, however, have not equally hard bones. The bones of fishes are comparatively soft; the bones of carnivorous animals comparatively hard. The bones of a manatee are so hard that when its skeleton was being wired together for the Royal College of Surgeons, the workman charged three times the usual price because of the difficulty of piercing the bones.

Now let us see how Nature makes bones.

At first in the embryo there are no bones at all, only membrane, and cartilage or 'gristle,' as it is commonly called. All the bones of the body, except the bones of the skull, are prefigured in cartilage: the bones of the skull are prefigured in membrane. But in the fifth week of fœtal life, lime begins to appear in the collar-bones, in the sixth week it appears in the lower jaw, and in the seventh week almost every bone in the body has a deposit of lime in it.

Let us see how one characteristic long bone, the thigh-bone, is made. At first, as we have said, it is pure cartilage; or rather, perhaps, we should say, pure cartilage and membrane, since the cartilage is surrounded by a layer of fibrous tissue —tissue, that is to say, composed of fine white fibres—which is known as the 'perichondrium.' Though the bone actually ultimately occupies the site of the cartilage, and though the lime is laid down in the cartilage, yet the perichondrium it is that makes the bone. For the perichondrium is the abode of the bone-makers. Who are they? That is a long question, and we must answer it slowly by degrees.

In the first chapter, when we were talking about the particles of cells which compose the body, we mentioned that there are thousands of free cells swimming in the blood and roaming about in the tissues. These free cells are of various kinds, and have various duties. Many of those swimming in the blood are phagocytes, that is to say, they eat germs and other foreign particles in the blood; many of those in the wall of the intestine are carriers of fat; many of those which wander about between the muscles make the thready, fluffy material known as 'connective tissue'; but they are all similar in their general structural character: they all consist of jelly-like living matter which has no cell-wall, and which moves about in a slithering kind of way, somewhat in the manner snails do by extending and contracting irregular arm-like processes of their substance. Little, tiny, crawling cells of the same general appearance are found in ditch water, and are called 'amoebæ'; and the microbes that cause malaria, and dysentery, and sleeping sickness, belong to the same class.

Now the membrane that covers the cartilage of bone is found to be the habitation of such wee, free, crawling cells. The side of the membrane next the bone is swarming with them, and, since each cell is only about $\frac{1}{2500}$ of an inch in diameter, there is room enough for millions of them in a single square inch.

These creepy, crawly cells it is that are the hod-men of the lime, and the sculptors of the bone. In the seventh week of fœtal life they begin their work in the thigh-bone about the centre of the circumference of the bone and work inwards from the circumference, weaving sheets of fine fibres, and

then plastering the fibres with carbonate and phosphate of lime so as to form thin curved plates of bone. Some of the plates form the hard outer rind of bone, and look, in cross-section, like the rings we see in a tree that has been sawn across; some of them surround the little tubes called 'Haversian Canals,' that run through the dense tissue of the bone; and some of them pack the spaces between the dense rind of the bone and the walls of the tubes. Between the plates there are thousands of little spindle-celled spaces, and in each of these one of the bone-building cells makes a home for itself. Once the plates are made the cells are imprisoned, but food can soak into their little chambers, and they are so close to each other that they can stretch out arm-like processes between the plates and touch each other.

So they go on building; but, meantime, in the early days of bone-making there have been other cells at work. The cartilage contains its cells too, and though they are cells with walls and without power of movement, they develop a penchant for bone-building too, and diligently surround themselves with lime. But they are not expert plasterers and bricklayers like the true bone-cells, and instead of making little dens for themselves, they succeed only in walling themselves completely in—in making catacombs or sarcophagi for themselves. Thus shut in, and deprived of food, they waste away and die, and the sum total of their life-work is a sort of irregular spongework of lime. Very unsatisfactory and incompetent work it is, and so the true bone-builders, the 'osteoblasts,' as they are called, seem to think, for soon they begin to invade it, and

break it down into larger spaces, and having broken it down they begin to replace it with the more elaborate bone they themselves make. But they do not replace it all, they leave a canal down the centre of the bone which is afterwards filled with white marrow.

At the point at which the true bone-cells invade the cartilage-bone, little tufts of blood-vessels project from the periosteum into the cartilage, and much of the bone laid down by the osteoblasts is laid down as tubes around blood-vessels. The cells which clear away the inferior bone which has been made by the cartilage-cells are not ordinary bone-making cells, but much larger cells known as 'osteoclasts' or bone-breakers, and until the bone is finished and perfected the osteoblasts and osteoclasts work side by side in co-operation.

This is how the bone is laid down in the centre of the shaft. But the thigh-bone is not all made at the same time. Not till a fortnight before birth does bone begin to appear at the lower end of the bone; not till the child is a year old does it appear at the upper end, and not till the twenty-first year do the various bony portions unite into one solid bone.

This is surely one of the most extraordinary things that has ever been discovered. Here are millions of cells crawling about here and there, weaving sheets of fine fibres, placing them in correct position, impregnating them with lime salt, clearing away old bone to make room for new bone, putting arches and buttresses just where they are needed, breaking down and building afresh until the bone is perfect. There are millions of them:

they are not connected with any central nervous system: there is no foreman, no master-builder, no architect to direct them, and yet they build the bone correctly according to specification, and then lie in their millions in little spaces between the bone-layers, apparently to keep the bone in good condition. Not only so, but they seem to have sense of time. On a certain date they begin the shaft, on another date the lower end, on another date the upper end, and fourteen or fifteen years later, they proceed to make a big knob at the top end of the bone. Further, if at any time the bone be broken, they proceed to mend it, and if the bone be badly set, they construct the bone in new ways so as to make it able to resist pressures in new directions.

More wonderful still, if a bone be cut out but the membrane or periosteum surrounding it be left, the osteoblasts and osteoclasts will endeavour to make, and will frequently succeed in making, a new bone. Once when Dr Joseph Bell, a well-known Edinburgh surgeon, was going his rounds at Edinburgh Royal Infirmary, a young man walked briskly into the ward. 'I have that man's thigh-bone in my surgical collection at home,' remarked Dr Bell. The thigh-bone had been diseased: Dr Bell had removed it, and the wonderful osteoblasts and osteoclasts had thereupon made a new one.

We see, then, that a bone is a very elaborate and complicated structure of lime. And it must be remembered, too, that a bone is living. Not only is it inhabited by millions of encloistered cells; but arteries, and veins, and lymphatics, and nerves run in all directions through it. More than two hundred

small arteries, for instance, enter the lower end of a thigh-bone, and each of the Haversian canals contains at least one blood-vessel.

When the bone is finished it is a mammalian bone, and there is hardly a ridge or mark upon it which cannot be found on the thigh-bone of a gorilla; but when Darwinians seek to explain this similarity by genetic relationship, they must not forget that the bones in both cases are made by millions of little, free crawling-cells which are capable of performing various functions under varying circumstances, and which could hardly have individually inherited such architectural co-operative capacity.

But there are occasions when the busy bone-builders make a bad job of it.

In ricketty children the bones lack lime and are soft and misshapen. The exact reason of this disease is unknown; but it is due not so much to lack of lime in the food as to digestive disorders and to unhygienic conditions. What the ricketty child chiefly needs is suitable food, fresh air, and sunlight. Without these the osteoblasts will not work.

In the strange disease known by the long name of 'osteomalacia,' which means bone-softness, the bones are originally quite well-made; but in adult life some or all of the bones begin to lose their lime and to soften. In time they come to consist of a shell of bone, and they are so soft that they can be easily bent and broken. Naturally any one suffering from osteomalacia becomes very bent and huddled up. A story is told of a man who was able to pack his wife, who was suffering from this disease, into a portmanteau and thus take her about with him without paying railway fare!

In the disease known as 'acromegaly' there is not too little but too much bone-matter. For some reason, after the bones are completely formed they begin to grow larger. The bones of the head, and hands, and feet, are especially affected, and the unfortunate victim of this trouble finds it necessary to buy larger and larger hats, and gloves, and boots. The nose, and chin, and cheek-bones also grow disproportionately larger. Perhaps the most interesting thing about this distressing disease is its probable cause.

At the base of the brain in front lies a body about the size of a bean called the 'pituitary gland.' What it has to do with the tiny cells that make bones—that make the bone of the great toe, for instance, five or six feet away—it is difficult to see; but it has been found that in cases of acromegaly this little gland is diseased and enlarged, and, therefore, there is reason to suppose that this gland puts some substance into the blood that influences bone-making. It gives us an idea of the mystery of the body when we think that our bones are at the mercy of this little bean-like gland.

Giantism, as we know, is a matter of large, or at least of long bones, and it also is not unlikely connected in some way with disease of the pituitary gland. The old stories of giants fifteen feet high or so are almost certainly untrue, but cases of giants over nine feet are well authenticated. The Russian giant Machkow, for instance, stood nine feet three inches, and his hand, measured from his wrist to the tip of his second finger, was two feet in length.

The bones in the human skeleton number altogether over two hundred. In the backbone there are 26;

in the skull 22; in the upper limbs 64, in the lower limbs 62; and there are 24 ribs. In the hand and wrist there are 22 bones.

Some of the bones, as, for instance, the bones of the skull, are fixed immovably together; but most of them are fixed together by movable joints which are cleverly and ingeniously devised. The ends of these jointed bones are covered with thin cushions of smooth gristle, and they are held together by bands and cords of strong white fibrous tissue which are known as ligaments. The ligaments are arranged in such a way as to permit all useful movements and yet to prevent dislocation; and so strong are they that it is often easier to break a bone than to dislocate it. Within the ligamentous capsule thus formed, a fluid is poured out to lubricate the ends of the bone and permit easy movement without friction.

The joints are of various kinds. There are hinge joints that allow bones to swing like a door on its hinges. Such a joint is seen in the joints of the jaws and the elbow. There are ball and socket joints where the end of one bone, shaped like a ball, fits into a cup-shaped cavity in another bone. Such a joint is seen in the shoulder joint and hip joint. It allows the upper-arm bone and the thigh-bone to be rotated on its own long axis, and also to be moved in any direction. There are gliding joints where bones are allowed to slide on each other for limited distances in various directions. Such joints are seen between the small bones of the wrist. There are pivot joints which allow rotation as a watch-key is turned in its keyhole. Such a joint is found between the top of the spine and the head.

When we consider the amount of movement that

takes place at some of the joints, as, for instance, when a champion club swinger swings Indian clubs for a hundred hours without ceasing—when we consider how smoothly and conveniently all the joints work for decade after decade, we are constrained to admire the wonderful mechanism of it all.

CHAPTER V

THE MUSCLES

Marvellous though the bones be, yet, devoid of soft tissues, they have little beauty. It is the muscles that give beauty to the lines of the body: it is the muscles that give expression to the countenance: it is the muscles that give man power of speech, and power of co-ordinated and purposive movements.

The man in the street is rather inclined to make a distinction between flesh and muscle; but flesh is just muscle, and muscle is just flesh. When we take the skin off any animal the red or pink flesh beneath is the muscle, and we find that it occurs in bundles, or bands, or sheets, and is usually attached at one or both ends to bone. When we investigate the minute structure of this flesh or muscle we find that it is thready, and that it consists of numerous little fibres, each about an inch long, which are fitted together into the muscle masses.

On examination of one of these muscle fibres we notice that it looks as if it were composed of alternate black and white rings, like black and white draughtsmen piled alternately on each other, and we notice, further, that it can be split up longitudinally into still finer striated fibrils. Each fibre is really just an elongated and altered cell, and on the outside of it cell-nuclei can still be seen. What is the meaning and nature of the striation we do not know—but, as we have said, it is seen only in

voluntary fibres in man. In the muscles of insects, which are specially powerful in proportion to their bulk, they are also specially well marked.

We are apt to think of muscle as solid; but muscle is only solid after its contents have coagulated, and in life it is probably always in a semi-fluid viscous condition.

Between the muscle fibres are blood-vessels, and lymphatics, and nerves. Each muscle fibre has its own motor nerve which ends on it in a branched sort of way, the ending being embedded in a little disc of granular-looking material known as the *end-plate.* The voluntary muscles have, of course, also nerves of sensation. The voluntary muscles are attached to bones by means of strong tendons such as can be felt in the wrist and behind the heel.

All the fibres of voluntary muscles, that is to say, most of the muscles of the body, have such a striated appearance as we have described; but besides voluntary muscles there are involuntary muscles, such as those in the muscular coat of the arteries, and the fibres of such involuntary muscles have their own special characteristics. They are spindle-shaped, they are only $\frac{1}{600}$ inch long, and they have no cross-striation. This absence of cross-striation is the distinguishing feature between voluntary and involuntary muscles. Involuntary fibres, like voluntary fibres, have nuclei. They are not quite separate and self-contained like voluntary fibres, for fine processes of cell-substance pass between adjacent cells like the band that united the Siamese twins. Further, involuntary muscle has two sets of nerves, one set to increase and the other to decrease its contractile activity, though it is capable

of rhythmical action on its own account without any stimulus from a nerve.

The muscles of the heart, though involuntary, are striated. When voluntary muscle contracts, it turns various bones upon their hinges, or fixes joints, or moves skin or cartilage, or compresses or propels the contents of sacs and cavities. Thus, the biceps muscle moves the elbow joint: the masseter muscle moves the lower jaw: the intercostal muscles move the ribs: the levator palpebrae muscle lifts the cartilage of the eyelid: the great muscles of the abdomen compress the abdominal contents. These are important functions; but the other muscles less known and less obvious which are not under the dominion of the will, and which are known as 'involuntary,' perform functions equally important. The muscle of the heart, the little hoops of muscle that surround the walls of the intestine and blood-vessels, the muscles that contract the iris and flatten the lens, play big parts in the commonwealth of the body.

The involuntary muscles act more slowly than the voluntary muscles. Jack Johnson can hit like lightning, but the little muscles that squeeze the blood along the arteries, and the lymph along the arteries, and the lymph along the lymphatics act in quite a leisurely fashion.

We make a distinction between voluntary and involuntary muscles, and the distinction is quite a good one; but it must be noticed that the distinction is not absolute in all respects. Involuntary muscles are never moved by the will. The heart goes its own gait; the gall-bladder squeezes out its bile quite unaffected by our will; but, on the

other hand, the voluntary muscles may sometimes act involuntarily. We tap a man's leg below the knee-cap, and the man's leg gives a little kick without the man desiring it; we tickle the sole of a man's foot and the muscles of the sole contract even against his will. Again, the muscles of a man suffering from strychnine poisoning or from lock-jaw undergo violent involuntary contractions; and in various spinal diseases involuntary and sometimes unconscious movements of voluntary muscles, no longer under the dominion of the will, frequently occur. Moreover all muscles, whether voluntary or involuntary, are constantly undergoing little involuntary twitches which keep them in a state of tonic contraction. From birth to death every muscle in a man's body is twitching at the rate of from forty to eighty twitches a second. We do not feel these twitches, we cannot see them, but it is possible to record them by means of a suitable recording instrument; it is possible to hear them by means of a stethoscope. Even without a stethoscope they can sometimes be heard. For instance, when we lie in bed we can sometimes hear a low booming and soughing in the ear that rests on the pillow, and this booming and soughing is really the sound of the little contractions of the masseter muscle which moves the lower jaw and is in close proximity to the ear.

The vigour of these little involuntary contractions varies from time to time. The limp, slack feeling produced by a hot bath, or by hot weather, is due in large measure to an actual slackening of the muscles, while the braced-up feeling that is produced by a cold bath or a cold breeze is due in

large measure to an actual tightening and bracing-up of the muscles. When we feel slack we really are slack, and probably many cases of laziness are largely due to inefficiency of the little involuntary twitches that give tone to the muscles.

At the base of voluntary contraction, then, are these involuntary contractions; and voluntary movements are little more than an exaggeration and application of these involuntary twitches. But more than that, even the large purposive movements of voluntary muscles are to a great extent involuntary, or effected, at least, without any precise directions from the will. There are several hundreds of voluntary muscles, and in most of our ordinary everyday movements these work not singly but in co-operative groups, performing complex actions that can be achieved only by most subtle and intricate co-ordination. In such cases the volition merely commands that such and such an action be performed, but the actual detailed co-ordination of the various muscles that play co-operative parts in the action is outside the will altogether. No man is conscious even of the muscles that enter into the achievement of the most simple action. He turns a corkscrew, but he does not know what muscles are concerned in the operation: he swims, but he does not select the muscles that perform the movements of swimming: he does not even know the names of the muscles concerned nor how many are employed, or to what extent each comes into play. Almost every action we perform could not be performed had we to prescribe the muscles necessary for the action, and to apportion the task of each. When we do

such an apparently easy thing as draw a deep breath, many muscles and millions of fibres contract and relax in mutual adjustment in order to produce the action. Not only are the muscles between the ribs at work, but also many muscles in the neck, and back, and chest, and abdomen, and each does exactly the right thing to produce a full entry of air.

Similarly when we stand, muscles all over the body are in action; for the balancing act is really quite a feat requiring a most marvellous accurate mutual adaptation of a multitude of muscles. To stand on one foot requires still more accurate equilibration, and to stand on tiptoe is almost a miracle in balancing. But the balancing is not a matter of the will: the requisite contraction and relaxation of the muscles are not directed by the will, they are largely under the direction of impulses sent out from the semicircular canals of the ear. We talk of voluntary locomotion; but if the management of muscles were left to our will we would walk about as gracefully and securely as a drunk man. We are largely puppets, and even when we achieve purposive actions our strings are pulled by subconscious forces. Our magnificent muscular machinery is too complicated for us to manage. In any complicated act we do not know exactly what muscles are moving, or the precise part each is playing in the resultant action. We merely *will* the action as a whole, and the muscles do the rest. Even Pavlova and Cinquevalli are puppets whose strings are pulled. We do little more with regard to the machinery of the body than to start it working, and to will what it is to effect, and the machinery

works on to the required end without our interposition, and almost without our consciousness. I resolve to go to the British Museum, and I start to walk there. But in one sense I do not walk there, I am walked there. I pay little attention to the movement of my legs. I walk along thinking of Amon Ra, or the Kaiser, or President Wilson, and I almost forget that I have legs at all, but the legs succeed in balancing me—they trudge on and on, and in time I reach my destination. So, again, a man can write his name automatically.

It is usually said that though most of our complex muscular actions are now automatic, they are originally volitional. It is said, for instance, that a man may be able to sign his name automatically, but that the child requires infinite pains in order to write at all. It is quite true that the child laboriously makes each letter, and requires a great effort of will to write at all; but, nevertheless, we maintain that the function is automatic from the first. The child at no time consciously co-ordinates the muscles concerned in writing: he merely concentrates his effort on the result to be obtained. He prefigures in his mind's eye an S, and by an effort of will—by a concentration of attention—induces the centres that co-ordinate his muscles to undertake and perform the task of writing an S. The action requires less effort in time, but from first to last the mind merely *wills* the result, and the detailed operations that achieve the result are outside the dominion of volition altogether.

And here we come at once into touch with the greatest mystery in the world. Here we come at once into grips with the mysterious relationship

between mind and matter, between body and spirit. What is will or effort, and how can such an immaterial thing as will set in motion to such good purpose all the complicated material machinery of the body? I wish to go to the British Museum, and I picture to myself in a vague general way the intermediary steps between here and there, and shortly my muscles begin to contract in wonderful ways and move me along to my destination. There is little correspondence between the act of will and the details of the process whereby the willed is attained: a Buonorotti sees a statue in the block of marble, and his muscles hew it out—but how do a vision and a wish set the machinery in motion to achieve such exquisite results? How does the desiring become doing? It may be said, of course, and is often said, that the sense of effort, the idea of volition are consequences of the same physical changes that cause the action—that the sense of effort is nothing more nor less than stirrings in the motor centres of the brain preliminary to the actual motion—that the desire and the deed are two sides of the same physical phenomena. This is quite possible, and the conception of motion as a consequence of volitional effort may be a delusion. But still there is some evidence to suggest that the wish does actually precede and cause the action, and that the wish is in some extraordinary way translated into heat or motion, or some of the other physical forms of force. There is nothing impossible, though a good deal bewildering, in such translation.

After all, a line between the physical and the psychical cannot be easily drawn; even heat, and

light, and motion are mainly subjective experiences. The explanation accepted by the average mind of a psychical causal antecedent for the motion of a pen—an explanation derived from the subjective facts of actual experience—is not unreasonable. It is almost impossible to believe that the collocations of material elements that result in living beings have taken place without prescience. Our mind, rightly or wrongly, will not admit such a possibility. It is almost impossible to believe that the motions of this pen, or of the molecules in the motor centres of the brain, are prior to the thoughts they seek to represent. Our own subjective perceptions inform us that a thought or volition of ours does often precede and condition motion, whether it be the motion of a bullet, of a leg, of a cricket-ball, or of a pen; and our reason goes farther than this, for, seeing that most of the biological facts of life seem of just such a special kind and character as our conscious and volitional actions, we may quite legitimately suppose that as our volition moves our limbs and our pens, so the volition of God moves our hearts, and the stars, and all other things with which we have no volitional associations. Briefly, we do certain things consciously and presciently, and it is not difficult to reason, therefore, and believe that all things are done consciously and presciently by an omniscient Power.

The tonic twitches that give tone to the muscles are of course invisible; but larger visible twitches of the voluntary muscles can be produced by stimulating muscles by electric discharges and in other ways. Such a twitch in man requires about one-tenth of a second for its accomplishment, or rather

from the time of the stimulus to the end of the relaxation following the contraction at least a tenth of a second must elapse. The muscle takes $\frac{1}{400}$ of a second to prepare to contract; it takes almost $\frac{4}{100}$ of a second to contract, and almost $\frac{5}{100}$ of a second to relax again That is the very quickest that muscle twitches can be produced in the muscles of a man, and if the muscles are tired, or if the man be of a lethargic temperament, the twitches will be much more tardy. We cannot twitch the voluntary muscles more rapidly than ten times a second, or six hundred times a minute, and if we try to obtain more rapid twitches by electrical stimulation, we will succeed only in producing a condition of chronic contraction. Ten twitches is the best a frog's or man's muscles can do, and a tortoise cannot manage more than one twitch a second, but an insect's muscles can do much better. Bees when fresh can vibrate their wings at the rate of 440 vibrations a second, giving rise to the note *la*, and when they are startled or excited they can move their wings even more rapidly till they sound a still higher note. Even the fly can flap its wings 335 times a second.

When, as we have said, we stimulate a voluntary muscle at a rate sufficient to provoke more than ten visible twitches a second, the result is to produce a contraction that continues for some time. Now, voluntary and many involuntary contractions of voluntary muscles are of this nature: they consist of groups of twitches provoked at a greater rate than ten per second—at a rate, indeed, of forty or fifty or eighty twitches a second. When we pull ourselves up by the biceps muscles the contracted muscle seems quite steady, but it is really twitching

at the rate of forty or fifty twitches a second. Even at rest, as we mentioned, the muscles are twitching at the same rate. What twitchy creatures we are!

These twitches, as we shall see later, are caused by discharges from the motor nerve-centres, but muscles can also twitch and contract of their own accord without any assistance from the nerves. By means of a poison called *curare* we can paralyse the endings of the nerves in the muscles, and after they are paralysed the muscle contracts when stimulated. Vapour of ammonia, again, which has no effect on nerves, will cause muscles to contract.

When muscle treated with curare to paralyse its nerves is stimulated, the contraction commences at the point of stimulation and runs along the muscle. In frog's muscle the wave goes at the rate of 3 or 4 yards a second, but in warm-blooded animals it goes about twice as fast.

One very interesting and strange thing about muscle fibres is that when they contract they contract to their full extent. There is no half-heartedness about them: they either do not contract at all or they contract to their utmost. But it may be said the extent and force of the contraction of muscles do vary. I may grasp a golf-club either vigorously or weakly. I may raise my foot either 3 inches or 20 inches. That is true; but the difference in the extent or vigour of any movement is not a difference in the extent and force of the contractions of fibres, but a difference in the number of fibres at work. Each muscle is made up of numbers of little muscle fibres each about an inch long. During the tonic contraction of rest a certain number of the fibres are twitching at the rate of

forty or eighty twitches a second, just as big twitches as they can; but when I move my muscles and grip a golf-stick, more fibres come into play, and when I grip more tightly more fibres still render assistance, until practically all fibres that can take part in the action are at work. But at all times whatever any fibre does, it does it with all its might.

So long as muscle is alive, chemical changes are occurring in it, and when it contracts the chemical changes proceed more vigorously. More oxygen is consumed and more carbonic acid is produced. An acid called *sarcolactic acid* is also formed. These are products of breaking down of muscle substance, and in order to make good the waste, muscle consumes an increased quantity of carbohydrate which it has stored up for its use. The chemical changes that occur in muscle give rise both to motion and to heat. One of the greatest discoveries of last century was the discovery of the transformation of energy—the discovery that heat, motion, chemical affinity, and electricity are interchangeable forms of energy. In muscle the potential energy of chemical affinity is constantly being transformed into heat and motion, even as in a petrol engine the potential energy in the chemical affinity of the petrol is transformed into heat and motion.

Between the heat and motion produced by the chemical changes in the muscle, a certain relationship obtains in so far, at least, as we find that every movement is associated with the production of heat, and the more the muscle movement the more the heat; but the proportion between heat and work is very variable, and depends on a great

variety of physical and physiological circumstances. In a muscle that is fresh and not tired, the energy taking the form of motion may be twenty-five per cent. of the energy taking the form of heat, whereas in a tired muscle, motion energy may be only four per cent. of the heat energy. As a rule, as the experiments of Atwater and Benedict have shown, twelve to twenty per cent. of the energy of muscle takes the form of motion, and eighty to eighty-eight per cent. the form of motion or work. The best triple-expansion steam-engines can only utilise as work about twelve per cent. of the potential energy of coal, and an ordinary locomotive only about four per cent., so that man, as a machine, is more efficient than a steam-engine.

Moreover, a piece of muscle weighing only 15 grains will lift a weight of 60 grains to a height of 13 feet, and consume in the work less than a thousandth part of its substance. The muscles of different animals, however, contain, bulk for bulk, different amounts of energy. Thus, it has been found that the muscles of the higher animals have, bulk for bulk, twice as much energy as the muscles of a frog; and it has been calculated that a dog fed on pure proteid food is able to convert into work forty-eight per cent. of the chemical energy of the food. A horse can pull only twice or thrice its own weight, while some insects can drag forty-two times their own weight. A Turkish porter has been known to carry five or six times his own weight, but an ant can carry a burden twenty-three times its own weight.

The lay mind is always inclined to find something electrical at the back of muscular contraction, and

though electricity is not the cause of muscular contraction, yet the chemical changes in the muscle that accompany contraction do cause electric currents in the muscle.

Muscles cannot contract and relax indefinitely for ever. After a certain number of contractions, or rather after the performance of a certain amount of work, the contractions become weaker, and shorter, and slower. The relaxation of the muscle is particularly slow and may occupy seconds instead of a fraction of a second. We say that the muscle is *fatigued*. Now, what is fatigue? In what does it consist? What are its causes?

In the case of muscles artificially stimulated the cause of fatigue is twofold. It is due, on the one hand, to the accumulation in the muscle of such products of muscle waste as sarcolactic acid: it is due, on the other hand, to the consumption of the chemical material whose changes produce the energy. If we wash out of a fatigued muscle the products of its own waste, it will again respond vigorously to stimulation; while if we inject lactic acid or the blood from a fatigued animal into fresh muscle, the fresh muscle at once gives indications of fatigue, which indications disappear if the lactic acid and pernicious blood be washed out again. In a living animal the circulation constantly washes the products of waste out of the muscle, and so the muscle constantly escapes fatigue or recovers from fatigue.

But even if we keep the muscle free from poisonous products there is the second factor of fatigue to be reckoned with. Unless the muscle also be supplied with food by the blood current, or

by some artificial means, it will come to a stop simply owing to lack of the material of energy. Poisoning and starvation are the two causes of muscle fatigue.

But the muscle fatigue of real life is due neither to poison nor starvation of the muscles. If the muscles in a thoroughly fatigued man are stimulated by an electric shock, they are seen to have plenty of energy in them. Even when Dorando fell from fatigue at the end of the Marathon race his muscles would, no doubt, have responded quite energetically to stimulation. What, then, is the nature of muscular fatigue in a living animal? There seems little doubt that in living animals so-called muscular fatigue mainly is fatigue of the central nervous system. The lactic acid and other waste products consequent on muscular work are washed by the lymph and blood currents out of the muscles and reach the brain and poison the motor centres there.

An Italian scientist named Mosso made classical experiments on the question of muscle fatigue by means of an instrument known as an ergograph, and demonstrated that fatigue is chiefly a matter of the central nervous system. He showed, on the one hand, that the failure of the muscle to contract under volitional effort is due not so much to impotence in the muscle itself, as to an impotence of the central nervous system due to the poisons created by muscular contractions thrown into the circulation; and he showed, on the other hand, that even as poisons created by muscle action hampered the working power of the central nervous system, so poisons created by brain-work and thrown into the general circulation diminished the action of muscle, partly no doubt by poisoning the central nervous system,

partly no doubt by also poisoning the muscles. His work in regard to the latter proposition was particularly interesting. He demonstrated by his ergograph that the delivery of a lecture reduced the lecturer's muscular energy sometimes in a marked degree. On 25th April, for instance, Dr Maggiora raised a weight of three kilogrammes by flexions of his middle finger forty-eight times, representing work of 7·161 kilogrammetres; while, on the next day, after delivering a lecture he could raise the same weight only thirty-eight times, representing 5·055 kilogrammes of work. The same doctor raised a weight of 500 grammes fifty-three times before examining twelve students, while after examinations he could raise the same weight only twelve times.

It would seem quite proven by these and other experiments that muscular fatigue predisposes to mental fatigue, and that mental fatigue predisposes to muscular fatigue. The old idea, therefore, that one might refresh oneself after mental toil by muscular labour is not sound. Fatigue is always general fatigue; it means certain substances in the general circulation which are best removed by rest and oxidation; it means also a certain depletion of the chemical substances of energy, and these can best be restored by nutrient food. Massage also relieves fatigue by assisting the circulation to carry away the products of muscle waste, and when an athlete is rubbed down after any violent or arduous muscular exercise, the procedure is quite in accordance with scientific principles.

Likewise, when the neurasthenic who is suffering from nerve fatigue is put to bed, fed up, given plenty of fresh air, and rubbed down, the treatment is

scientifically sound. But the weary business man, the overtaxed brain-worker, who tries to relieve mental fatigue by exhausting Alpine expeditions or walking tours will not succeed in relieving the fatigue, but will probably aggravate it. And here we may notice the law that it never pays to work through fatigue. A tired muscle is an inefficient muscle, and a rest taken in time will so far increase the efficiency of the work that the time lost over the rest will be more than made up, for the time required to recuperate a muscle greatly fatigued is much greater proportionately than the time to recuperate a muscle only slightly fatigued. If, for instance, the period of rest required by a muscle completely exhausted after thirty contractions be an hour, the time required to rest a muscle after fifteen contractions will be only a quarter of an hour. A man with a strong will can force himself to work in spite of fatigue both of body or mind, but the work done is inefficient, and much time will be required to restore body and mind to normal efficiency. Indeed, it would seem that fatigue pushed beyond a certain limit permanently impairs efficiency both of mind and body.

It must be recognised, too, that it is less conducive to fatigue to accomplish the same work by many moderate contractions than by a few large and violent ones. Thus it is very fatiguing to climb to the top of the Great Pyramid; while the same height may be ascended by small steps without incurring any fatigue at all.

In all matters of fatigue, however, it is to be remembered that individuals are subject in different degrees to fatigue, and that some are easily fatigued

mentally and others easily fatigued bodily. It is to be remembered, too, that training and habit, especially in youth, will render individuals much more immune to fatigue. How exactly training and habit act it is impossible to say; but it is a well-known fact.

Professor Aducco found that after a month's practice his middle finger could do double the work with the ergograph it was capable of when he commenced experimenting, and in all departments of work, whether mental or physical, we see the same law obtain. Indeed, all the various systems for developing and strengthening the muscles are based on this principle.

CHAPTER VI

THE MUSCLES—*Continued*

The muscles are very wonderful things: a muscular man is a very wonderful work machine, and often a very beautiful picture, and from the time of Hercules to the time of Sandow men have desired big and strong muscles. The worship of muscle has its wise side, and its good side, and its moral side, but it has also its foolish side, and its bad side, and its immoral side, and, carried beyond bounds, as it often is in England, it is capable of doing much harm.

There are three main advantages of muscular power: it enables a man to do good muscular work: it enables a man to indulge in pleasurable exercises; and it gives æsthetic pleasure to the beholder. Sir Frederick Treves has declared: 'Physical exercise is capable of healthfully transforming the meaningless, monotonous, purposeless curves of the physically uneducated, who are mainly muscular paupers whose limits are little better than burlesques, composed as they are of shapeless masses of flabby, doughy tissue covered with dull, loose, lustreless skin, into the beautiful, classical, muscular outline of ancient statuary clothed with the polished, fresh, elastic skin of perfect health.'

That, no doubt, is rather too optimistic, but there is some truth in it. The muscles are meant to be used; they are meant to be developed; they are meant to be a source of pleasure. But muscle force,

after all, is brute force, and, in respect of muscle force, most of the brutes can beat man. What chance has a Sandow or a Jack Johnson against a gorilla? What champion trapeze performer can compete with a monkey? There is very little advantage to most men in the possession of huge muscles and enormous muscular strength, and the acquisition of them requires the expenditure of a vast amount of nerve energy that might be much better expended. Moreover, the work involves fatigue, and even if the fatigue does not sensibly affect the motor centres of the muscles, it often sensibly affects the thinking powers of the brain. When the strong man uses his brains he becomes tired at once. It is very possible that the strong man suffers from muscular fatigue but does not recognise it, and that the mental debility is sign and symptom of general fatigue.

In just the same way a man may not know that he is mentally fatigued till he attempts some manual labour, when he soon discovers that he 'has taken it out of himself.' The one man is so accustomed to muscular fatigue that he does not notice it, and has such margin of muscular strength that he does not detect the inefficiency of fatigue: the other man is so habituated to mental fatigue that he does not feel it, and does not recognise that his brain-work has deteriorated. But in both cases there is general fatigue evinced most clearly where each is weakest. It is amazing how quickly some mental workers are overtaken by physical fatigue if they attempt physical work: it is equally amazing how quickly some muscularly strong men are overtaken by mental fatigue if they begin to use their brains.

Mosso, in his work on fatigue, mentions the case of great strong soldiers perspiring till drops of sweat fell upon the paper, when they were obliged to write examination papers to prove that they were not illiterate.

Quite apart from any toxicity, it is quite possible that muscular fatigue causes an actual anæmia of the brain. Mosso examined the brains of four pigeons that had flown from Bologna to Turin, and found them pale and bloodless. It is well known that excessive muscular fatigue will render even the most intellectual stupid and dull; and cases have been known where the toxic products of excessive muscular exercise have caused actual delirium or insensibility. Excessive muscular exercise and excessive muscular development, therefore, have this danger and drawback, that they are apt to detract from mental energy and from mental development. Still, while we recognise this, we must also notice that there are tremendous natural differences in resistance to muscular fatigue, as well as to mental fatigue, and that many men may perform great amounts of muscular work and yet show no symptoms of fatigue either in their muscle power or their brain-work. We find this difference in all animals. Kronecker found that when the muscles of various dogs were artificially stimulated, some would contract only 150 times, while others would contract 1500 times.

The question of the relationship between size of muscles and power of muscles is an interesting one. As a rule, muscles enlarge with exercise, and, as a rule, large muscles are strong muscles; but, as we have seen, it is the central nervous system that sets

the limitations to muscular work; and it is very likely that large muscles mean more waste products, and a quicker poisoning of the central nervous system. In a general way large muscles seem to be developed by violent actions and quick feats of strength, and to be useful for such purposes; while for prolonged activity the smaller wirier muscles seem more serviceable. The Arab, whose leg muscles are of the most meagre description, will easily outrun a man with the leg muscles of a Sandow, and will carry a burden for miles that would tire a man with larger muscles in a very short time. Again, it must be recognised that there is the question of quality as well as quantity. Bulk for bulk, the muscle of an average man has twice the power of the muscle of an average frog; and bulk for bulk, the muscles of an ant are many times stronger than the muscles of a man. What is to be desired, as a rule, are not large muscles, but muscles able to carry out efficiently such work as may be pleasurable and necessary, and there is undoubtedly more pleasure to be obtained from a skilfully manipulated mashie than from a sledgehammer; and the efficiency is of a higher order. Not in strength but in efficiency and co-ordination do the muscles of man surpass the muscles of the lower animals.

A few efficient co-ordinated muscles round the thumb, a few little muscles in the larynx, have more to do with the supremacy of man than any power of biceps or triceps. A camel can carry a pretty heavy burden, but a camel cannot dance like Pavlova or Njinski. A bear can hug better than Hackenschmidt, but a bear cannot compete with a Michael Angelo. In ancient days, when a man carried his

life in his hands, muscular strength and brute force were worth possessing, but now man carries his life in his head the worship of big muscles is without much excuse and without much reason, especially since it is associated with the dangers and drawbacks we have already indicated. For most people, muscular development beyond a moderate extent does not make for health, does not make for energy, does not make for usefulness, and is a waste of time. Further, there is a tendency for big muscles in middle life to degenerate and turn into fat, and at all times their upkeep means a tax upon the nerves, the circulation, the digestion, and the excretory organs.

To general athletics there is the same objection to be taken; and the place of honour the athlete holds in England is little short of absurd. What are exactly physical qualities—what are exactly the structural and physiological characters that enable a man to run a hundred yards in less than ten seconds, we do not know; but the feat is of no importance; it can be performed by the athlete only for a few years, and it is liable to damage the much more valuable muscles of his heart. The glorification of muscular skill and muscular strength has very little sense in it. Some sense it *may* have, for, indirectly, it may lead to self-discipline, and fresh air, and to an avoidance of unhealthy manner of life. It may also conduce to a saving scorn of laziness, cowardice, weakness, and inefficiency; but to judge from the physical character of the crowd that watches football matches and athletic sports, its influence for good is not very effectual. In another indirect way glorification of muscle may work good. The motor centres

in the brain are closely associated with the speech centres, and probably all thought has a motor basis—I cannot think of a circle without rolling my eyes, I cannot frown and feel merry—and it is possible that athletic stock may have great mental potentiality. On the whole, however, there can be no doubt at all that in England the worship of sport and of muscular performances is carried to a ridiculous extreme.

There is much talked and written nowadays about the improvement of the physique of women consequent on indulgence in physical exercise. It is perfectly true that women have increased in stature and in muscular power, but it is very much to be questioned whether this is a good thing, and it is very much to be questioned whether the modern athletic woman is a satisfactory organism from either a eugenic or a social point of view. We often hear that the improved physique of women means an improved physique of their offspring, but any one with the most elementary knowledge of heredity ought to know, in the first place, that acquired characters are not inheritable, and ought to know, in the second place, that in most cases stature as a germinal character is inherited from the father. There is no ground at all for supposing that the big athletic woman will have bigger or healthier children than the shorter domestic woman of Victorian times. On the contrary, there is every reason to fear that the modern athletic woman has developed her muscles at the expense of energy intended to be used for purposes of maternity. A woman six feet high is no more fitted to bear handsome, healthy children than a woman five feet high, and *ceteris paribus*, the

sons and daughters of the latter are just as likely, perhaps more likely, to be tall and strong as the sons and daughters of the former. So far as physique goes the best qualification for maternity is simply a roomy pelvis.

The perpetual motor activity of the modern woman may develop her stature, but it certainly does not fit her for motherhood, and, in many cases, it leads to complete nervous breakdown and to neurasthenic sterility. A woman for purposes of child-bearing is dowered by nature with great stores of vital energy; but the modern woman squanders this energy in muscular movements, and the results are barrenness, emotional aridity, and hysteria. Physical movement has become quite an obsession with average modern English women. They seem unable to divert any energy into emotional or intellectual or spiritual channels: they live to swing their arms or to point their toes. Life to them means a perpetual restless round of dancing, golfing, tennis-playing, motoring—motoring, tennis-playing, golfing, dancing; and spiritual, emotional, and sexual sterility are the consequences. There are, of course, exceptional women who live exceptional well-balanced lives—women who realise that happiness consists in a duly proportioned satisfaction of all their faculties and capacities; but no one with any knowledge of the lives of the modern leisured classes can deny that the modern woman is a victim of her muscles, so much so that she has no time to think or to feel. It is an amazing thing to find that in these days when a certain section of women are crying out for opportunities to do man's work in the world, and to share man's political responsibilities in

a man-made world—it is amazing to find in these days that the vast majority of young leisured women use their unlimited leisure and opportunities in muscular contractions detrimental at once to their beauty, to their character, and to their health, however conducive they may be to their muscular development.

And here let it be noted that women are not designed for these continual muscular contractions. One has only to watch boys and girls at play to see that the boys have naturally a much larger amount of muscular force and muscular co-ordination than the girls, and take much more naturally to games where these are required. Further, a little knowledge of physiology teaches us that man has more furnace capacity than women; that they burn quicker, and that they are meant as certainly for muscular activity as women are meant for muscular ease. The antimacassared ease of early Victorian times may have been too much of a good thing; but even that was better than the athletic excesses of modern days.

All this does not mean that muscles are not meant to be used: it means only that muscle is not to be unduly worked or unjustly worshipped. The man or woman who takes no physical exercise, who sits in an office or lolls in a drawing-room all day long, is bound to degenerate both in muscular and nervous strength, and can never enjoy full health. Mind and body are related: there is much truth in the expression *mens sana in corpore sano*, and exercise within judicious limits makes for the health of both. The contractions of the muscles move not only the man from place to place, drive not only the golf-ball from hole to hole, they also assist in the

circulation of blood and lymph. The mistake is to make exercise an end instead of both an end and a means: it is, if rightly used, a pleasurable activity, but it is also a means of strengthening a man's higher faculties of mind and soul, and for fitting a man to live an energetic and healthy intellectual and spiritual life,—a life that will persist long after the muscles have lost their elasticity and vigour.

Even as there are men born with extraordinary mental strength, so there are men born with extraordinary physical strength—men whose muscles have tremendous contractile force and are apparently immune to fatigue.

We have spoken a great deal about the contraction of muscles, but so far we have not faced the problem of the nature of contraction. That is one of the most difficult problems in the world, and so far it has not been solved.

We find, even in the most primitive forms of life, contraction. The amœbæ in the slime crawl about by contractions and relaxations of their substance, comparable to the contractions and relaxations of the muscles of higher animals; but no one has yet explained the mechanism of even such simple movements. Nevertheless, a certain amount of dim light has been thrown upon the matter. Energy must come from energy, that is certain. Where then does the energy of muscular contraction come?

The energy undoubtedly comes from the potential energy of the food we eat, and, therefore, if we go far enough back, from the energy of the sunlight which breaks up the carbon-dioxide in the chlorophyll of the green plant and binds together the starch and sugar. It has been proved that all the

heat and all the energy, in the form of work, produced by an animal can be accounted for by the energy, in the form of heat, produced by the oxidation of the food that the animal consumes. Suppose a man burns or oxidises enough butter to raise the temperature of a kilogramme of water one degree Centigrade. If he eats that same amount of butter, he will have at his disposal, in some form or other, that amount of energy. If we burn butter in a dish, all the energy of the burning butter is turned into heat; but when we eat butter and burn it slowly inside us only about 80 per cent. of its energy is turned into heat, while about 20 per cent. appears as muscular work. Now the question comes to be, How is the 20 per cent. of the energy of the butter, or of any other food, turned into work? We can quite easily understand how it might be converted into heat, but it is not so easy to understand how the energy is converted into work. We might easily turn part of the energy of butter, or any other food, into work if we had a steam-engine, by using part of its heat to turn water into steam; but there is nothing in a muscle that would enable heat to be transformed into energy in such a manner. It is possible that part of the energy of food is transformed into work by a roundabout route. Twenty per cent. of the energy is turned into chemical energy, and breaks up part of the muscle substance into carbonic acid and lactic and other waste products, and these extra molecules affect the surface tension of the contractile portion of the muscle fibre, or alter its surface tension in such a way as to give rise to an inrush of fluid and an alteration in the shape and tension of the muscle.

Let us see how this happens. First take surface tension. Surface tension is the cohesion between the molecules at the surface of a liquid. It is surface tension that rounds a tear or a globule of mercury running about on a plate. Now any chemical change in the surface of a globule in such a condition of surface tension will alter the degree of surface tension and alter the shape of the globule, and so the chemical change produced in a muscle by the breaking down of the muscle substance into carbonic acid and lactic acid may be supposed to alter the surface tension of certain of its globules, and thus alter its shape.

Take the case of osmosis. If we put a solution of albumin into a membranous bag permeable to water but not permeable to sugar, the water will stream into the bag and distend it, and if we could suddenly break each molecule of albumin into two, the water would stream in much more strongly and still more distend the bag. The streaming in is known as osmosis. Now the contractile portion of the muscle fibre may be supposed to be a solution of certain proteid material in a bag surrounded by water, and if the proteid matter within the bag break down, as it is supposed to do under the chemical energy of oxidised food, the bag will be distended by osmosis.

The explanations are not very satisfactory. Osmosis and surface tension may have something to do with muscular contraction; but we have no clear understanding of the process. Whatever the process may be the results are marvellous; by a little water flowing into little bags, by a change in the tension of little globules, what has been done in

the world! By muscular contractions Shakespeare wrote his Plays; by muscular contractions Phidias carved his statues and Titian painted his pictures; by muscular contractions men have cut America in two; by muscular contractions men have solved some of the deepest problems of the world.

CHAPTER VII

THE NERVOUS SYSTEM

The nervous system, as is well known, consists of the brain, and the spinal cord, and all nerves and nerve-cells in connection therewith. It is closely and mysteriously connected with movement, with sensation, and with all the physiological processes of the body. The muscles, as we have seen, *can* contract quite independently of the nervous system, but they seldom or never do so: all the movements of the body, all the physiological processes in some measure are under the control of the nerves.

The most obvious parts of the nervous system are the spinal nerves coming from the spinal cord and going to the skin and skeletal muscles. These spinal nerves look like white glistening cords and threads, and were for long considered of the same nature as tendons. We need not consider their microscopic structure more than to mention that each is made up of fine fibres bound together in a common sheath. Some of the fibres are afferent fibres which conduct impulses towards the brain, and others are efferent fibres which conduct impulses from the brain towards the circumference. The afferent and efferent fibres arise at the same level from the spinal cord but separately, and join a little way from the cord into the single nerve. Each nerve-fibre, remarkable to relate, is really a long arm of a nerve-cell. The afferent fibres which

conduct impulses towards the brain are outgrowths from cells situated on it just before it issues from the spinal cord, and the efferent fibres are outgrowths from cells situated in the spinal cord itself. If one in any way separate the nerve from its cell it will die. It is an amazing thing to think that little microscopic cells can send out arms, feet and, in the case of the larger animals, yards in length. In the same proportion our arms would be many hundred miles long. It is an amazing thing, too, to think that destroy the little microscopic cell and the whole length of nerve-fibre must die. But a more amazing thing still: if the nerve-fibres be cut from the cells, the cells are capable of growing new fibres. The nerve-units, it will be seen, are not nerves and cells, but cells with their nerves, the cell and nerve-fibre together being now called a 'neuron.'

Nerve-cells have usually many branches; the long branch which becomes the nerve being called the 'axon,' and the other shorter branches being termed 'dendrites.' The dendrites are very numerous usually, and are usually in close proximity to dendrites of other cells, but the dendrites of adjacent cells only intertwine, never join. The axon itself always ends by dividing into branches, and the branches in some cases embrace a cell. Each muscle-fibre has its own nerve-fibre and bones, and cartilages, and arteries, and veins, and lymphatics, and internal organs are richly supplied with nerves. Altogether there are millions and millions of nerve-cells with axons and dendrites going in all directions. In most cases, the cells are arranged in little groups, each little group being called a 'centre,' and being concerned with some physiological

function of a particular part. Thus we talk of the 'respiratory centre,' the speech centre, the motor centre for the thumb, and so on.

Now what do we know of the meaning of this multitudinous and complicated apparatus? We have divided nerve-fibres into afferent fibres, or fibres sending impulses to the brain, and efferent nerves, or nerves sending impulses from the brain, and we have said that ordinary spinal nerves are composed of both. What do we mean by sending impulses to and from the brain?

We mean that any stimulation of afferent fibres by electric current, or injury, or any other way, causes a brainward propagation of some sort of molecular excitement that reaches and physiologically affects cells in the brain; and we mean that any stimulation of efferent fibres causes some sort of a molecular excitement which is conducted in a direction away from the brain to produce some physiological effect in some more peripheral part. The physiological effect of the afferent fibres is sensory, and the physiological effect of the efferent fibres is often motor, so that they are often called respectively 'sensory' and 'motor' fibres. It is all a matter of physiological experiment. If, for instance, we cut the nerve going to the flexor muscle, and stimulate by an electric current the end of that part of it that goes to the flexor muscle, the muscle contracts; while if we stimulate that part of it still connected with the central nervous system and going towards the brain, we produce a sensation of pain. Under normal conditions, the afferent nerves are excited only by stimuli from the periphery; and the efferent nerves by stimuli in the spinal cord or

brain. Thus, if I burn my finger, the peripheral stimulus runs as a molecular disturbance along the afferent fibres of the spinal nerve supplying the finger, and finally reaches the brain where it gives rise to sensation. Again, if I will to move my foot, a molecular disturbance concomitant with the volition, or caused by it, commences in the motor centres in the brain, and is propagated down the spinal cord and along a spinal nerve till it stimulates certain muscles of my foot and causes them to contract as I desire.

Efferent Fibres.—The efferent fibres in the spinal nerves which send impulses from the brain to the periphery terminate in their cells, which are situated, as we have said, in the spinal cord. The efferent fibres of the spinal nerves reach to their cells in the spinal cord and no farther, and cannot, therefore, themselves send impulses from the brain. But their cells are brought into communication with the brain-cells by axons from the brain-cells that pass down the cord and embrace them with their branches. The brain-cell puts out an arm and touches the spinal-cell, and the spinal-cell puts out an arm and touches the muscle or other peripheral tissue. The motor-cell in the spinal cord is, therefore, an emissary between the brain and more peripheral parts. There is a system of relays.

Many of the spinal efferent fibres are musculo-motor, that is to say, they cause the muscles to contract, but they perform various other functions, too. Thus some impulses down the spinal efferent nerves keep the muscles in tone, and others seem to favour its nutrition. Some very fine efferent fibres, known as sympathetic fibres, which transmit their

impulses through intermediary neurons, regulate the involuntary muscles causing them to contract and relax.

Beside efferent fibres that come from the brain in the spinal nerves there are others that come from the brain, and bulb of the brain, along with the so-called cranial nerves (*e.g.* the nerves of smell and hearing), and some of these move the muscles of the eyeball, and others regulate the secretion of the pancreas, salivary, and other glands.

It is rhythmical impulses from the efferent fibres of spinal nerves that cause the constant rhythmical twitching of the voluntary muscles. All life long a certain number of the little motor-cells, to which the efferent fibres belong, send out little impulses at the rate of forty to eighty a second. That is surely rather wonderful.

Afferent Fibres.—The afferent fibres of the spinal nerves are outgrowths, as we have said, of nerve-cells which are situated near the spinal cord. Now this cell not only sends an arm down towards the periphery (to the skin and muscles, for instance), but it also sends a branch or axon up along the cord to the brain, where it terminates by branching and embracing a brain-cell. Impulses, therefore, started by some stimulus, such as heat or cold, at the periphery, pass up the nerve and transmit the molecular disturbance to the brain-cells. Some of these afferent impulses appear in consciousness as sensations—sensations of heat, and cold, and pain; of others we have no consciousness at all. As in the case of efferent fibres there are fine afferent fibres, known as sympathetic fibres, which send impulses to the brain from the glands and from

the involuntary muscles of the viscera, and these impulses again may appear in consciousness as discomfort or pain.

The most important of all afferent fibres, however, are the afferent fibres of the nerves of seeing and hearing, which are not spinal but cranial nerves. To describe the wonderful apparatus of these special senses would require more space than we have at our command; but we all realise the marvellous nature of the eye and ear, and the wonderful messages which their afferent nerves send to the brain.

We have spoken, for simplicity's sake, as if the afferent impulses of the spinal afferent fibres were afferent impulses and nothing more. But every afferent nerve, as it passes brainwards along the spinal cord, gives off branches that embrace and excite the cells of efferent fibres in the cord, and all afferent impulses when they reach the brain also pass on their excitement to efferent centres. Francis Thompson writes, 'You cannot stir a flower without troubling of a star'; and it seems you certainly cannot have an afferent impulse without exciting an efferent impulse, either in the cells of the brain or spinal cord. There is probably no such thing as an isolated afferent impulse. Every efferent impulse is continued in spinal cord or brain as an efferent impulse, and in normal conditions afferent impulses initiate or modify all the physiological processes of the body.

When the efferent impulse takes place without any instigation of the will, the physiological result of the efferent impulse is known as a reflex action. The reflex action may be conscious or it may be

unconscious, but it is a result of afferent impulses and is not volitional. Thus if the sole of my foot be tickled, the afferent impulse excites motor centres that cause contractions of the foot muscles. That is a reflex action, and since it excites involuntary motion it is called an excito-motor reflex. Again, if I smell appetising food, the afferent nerve of cell excites an efferent centre of secretion and my mouth waters. That also is a reflex action, and, since it excites involuntary secretion, it is called an excito-secretory reflex.

Such reflexes are obvious examples of involuntary efferent impulses following afferent ones, and they occur, as a rule, in the consciousness, though they will occur just the same in an unconscious subject; but there are hundreds of much more complicated insensible and obscure reflexes that are constantly following afferent impulses, since every afferent impulse has its efferent consequence, and few of these are voluntary. Even the greater part of so-called voluntary actions are really reflex actions. For instance, we voluntarily, as we think, bend our elbow; but the volition itself acts in a reflex way, for it excites, without its own direction, a multitude of motor centres which, quite apart from specific direction of the will, carry out its wishes. Further, one of the essential features of flexion is not even suspected by the volition, and is purely an excito-muscular reflex. In order that the muscles of flexion may act, it is necessary that the muscles of extension relax, and this relaxation is caused by afferent impulses from the muscles of flexion.

In every muscular act, voluntary or involuntary, antagonistic muscles must be slackened, and all

these slackenings are excito-motor reflexes. We are balanced in an upright posture not by the action of the will, as we think, but by a most complicated series of afferent impulses from the soles of the feet, from the semicircular canals of the ears, and from other parts of the body, which result in exactly the right motor impulses being sent to exactly the right muscles. It is usual in text-books of physiology to talk of such co-ordinated muscular acts as balancing, which require to be practised and learnt as volitional acts that have become reflex by repetition; but that is sheer nonsense. At no time were the acts other than reflex, and, though education may render conscious effort of will less necessary, from first to last, the details of the action are reflex. Let a man have loss of sensation in his soles, and disease of his semicircular canals, and he will soon discover how little volition regulates his equilibrium. A frog which has had its brain destroyed will make skilful efforts with his leg to remove an irritant from his flank, and if one leg be held will use the other. But there is no consciousness to guide the complicated movements.

The main objects of the millions of cells, and axons, and dendrites in the spinal cord and brain seem to be to link together afferent and efferent impulses in such a way that afferent impulses will result in actions and processes useful to the individual, and render all the actions of the body as independent as possible—as independent as possible in detail at least—of the will. The will merely wishes: the reflexes perform. Impulses lead to impulses in a most wonderful way by means of

most intricate collocations and combinations of nerve-cells and nerve-fibres, and we are really creatures of impulse and automata very much at the mercy of environmental stimuli. There are more afferent than efferent nerves, and all actions seem to be started by afferent impulses that go just where they ought to go. This is noticeable not only in afferent messages that appear in consciousness, and result in efferent impulses that seem to be under the control of the conscious will; but even more so in the actions that go on outside consciousness, and without any superintendence of the will at all. The heart, the lungs, the blood-vessels, the glands, the kidneys, the liver, every organ in the body, in fact, are all most beautifully and subtly worked and regulated by afferent impulses that excite just such efferent impulses as result in actions and processes good for the organism.

Let the skin get a little too hot, and afferent impulses go off which excite efferent impulses, which result in a secretion of sweat and in a dilatation of the blood-vessels of the skin, and so the skin is cooled. Let there be too much carbon-dioxide in the blood, and afferent impulses from the nerves of the respiratory excite efferent impulses which result in stronger movements of the muscles of respiration, and better ventilation of the lungs. The idea is ingenious, the mechanism is marvellous. A few reflexes we know, but there must be thousands and millions we do not know, for, as we remarked, each afferent impulse results in efferent ones, and all the efferent functions together make up the total functions of life. The will has little to do with the essentials of environment, with air, with light, with

warmth, with odour, and it has little to do with the performance of the actions and processes which are the reflex result of environmental stimuli; but this wonderful association of explosives reacts night and day to stimuli and produces all these extraordinary results.

Think of this extraordinary collection of millions of cells and millions of fibres all acting and re-acting in thousands of co-operative groups, efferent impulse answering afferent impulse, with the wisdom, and precision, and prescience of a Solon, with a delicate physico-chemical ingenuity that no Faraday or Kelvin could emulate, with results as amazing as all the functions, and feelings, and thinkings of a man! Think of it! Millions of these cells vibrate at the rate of forty or eighty vibrations a second for years and years. Little groups of them are looking after the blood-vessels. Little groups of them are engaged in watching the breathing. Little groups of them are engaged in balancing and performing other complex co-ordinating movements. Little groups of them, under very mixed and complex afferent impulses from the eyes, and joints, and cerebral cells, are moving this pen across the paper. Little groups of them are translating the molecular excitement produced in them by afferent impulses set up by invisible waves of ether or air,—are translating this excitement into colour, and beauty into sound and music. Little groups of them it was that, under the influence of environmental stimuli, made Shakespeare think and Shakespeare write.

The intricacy and multitudinousness, the delicacy and precision, of the network of cells and fibres, of discharging stations and receiving stations, baffle

the imagination. And yet Darwinians dare to assert that all this delicate intricate machinery made to produce such amazing results has been produced simply by the selection by environment of experiments good, bad, and indifferent, made by Nature! All these million cells so bound together, so balanced together, in explosive association, produced by Nature selecting and rejecting in the course of experiments made without prescience and purpose! What can an intelligent and unprejudiced man say but—'Bah!' Mind is behind this marvellous intricacy of cause and effect of air and breathing, of ether waves and light, of air waves and sound. It was not experiment that discovered that ether waves breaking on certain molecular combinations would cause colour. It was a Mind that made the two cause and effect, and that prepared the apparatus to make colour and beauty out of such a relationship.

We never know exactly how far afferent impulses reach, and how many efferent side currents they may produce. A few black marks on a telegraph form, 'So-and-so is dead,' what whirlpools of afferent waves they may produce. A tooth cutting a gum in a child may produce convulsions; a little pressure on a tender corn may evoke both great pain and great eloquence.

In a general way, apart from disease, the higher an organism the more will afferent impulses produce efferent consequences in his consciousness, and the more wide reaching will the conscious consequences be. It is consciousness, breadth, and depth, and height, and sensitiveness of consciousness that determines the place of a man among living organisms. One man may see the lid of a

kettle jumping with the pressure of the steam and have a vision of a tea-pot. Another man may see the same kettle-lid and have a vision of a locomotive. And we all know how differently beauty of form or beauty of sound affects different people.

But here we come into touch with the very difficult question of associative memory, a subject too difficult to discuss in these pages.

Before, however, completely leaving the question of afferent and efferent nerves, we may point out that probably without any afferent impulses there would be no efferent impulses at all, and the organism would die. Sleep, which is brother to death, is mainly the result of a partial stoppage of afferent impulses by a blockage of the afferent impulses where they reach the nerve-cells in the cerebrum, and if *all* afferent impulses were blocked, sleep would become the sleep of death.

Some years ago, a boy known as Strümpel's boy, was the object of much study. This boy did not feel pains, had no sense of touch or taste. He was also deaf in the right ear and blind in the left eye. The result was that he went sound asleep if his right ear was stopped and his left eye bandaged. If all the afferent impulses going to the heart could have been blocked, the heart would have gone to sleep also.

In hypnotic conditions afferent impulses are prevented from reaching the cells of consciousness in the brain, and yet other afferent paths are left open so that sounds and sights may cause their usual associative efferent excito-motor effects. Thus if a man see a cup of coffee, the afferent impulses from his eyes excite the motor centres in his brain,

and they, without any instigation from the conscious, will promptly set in motion the various muscles that raise a cup of tea to the lips. This, in fact, often happens in waking life when the mind is preoccupied with other things. The sight of food provokes the unconscious consumption of it.

An interesting question arises. Do the conscious sensations depend on the afferent nerve, on the afferent stimulus, or on the recipient nerve centre? Helmholtz declared that if we could fix the peripheral end of the auditory nerve to the eye, and the peripheral end of the optic nerve to the ear, we should hear lightning and see thunder. Such an experiment is physically impossible for many reasons, but an experiment on similar lines has been successfully performed. A nerve that normally sends impulses to the heart, that slow or check it, was grafted on another nerve that dilates the pupil, and on stimulating the grafted nerve the pupil was found to dilate. It would seem then that the effect of a nerve impulse depends on the nature of the centre that receives the stimulus, and not at all on the nature of the nerve conducting the impulse. Again, the vibrations of a tuning-fork placed on the skin of the finger are felt as vibrations, but by the ear they are heard as sound; but it is the nature of the cell recipient of the nerve impulses that gives rise to the different sensations. So that it is not the nature of the stimulus that produces the effect, the effect is due simply to the molecular nature of the centre which is excited. A blow between the eyes that stimulates the nerve centres of hearing will produce a sensation of light just as surely as waves of light do. 'Waren nicht die Augen

sonnenhaft wie Können sie dann die Sonne erblicken,' is true enough if we substitute for eyes the central cells of sight. The light is not in the sun, but in the cells of sight: the sound is not in the bell, but in the cells of hearing. But to this metaphysical question we must return later in our chapters on the Brain and Mind.

We do not know much with regard to the chemico-physical nature of the molecular movements in nerves and nerve-cells that result in sensation and movement. It is not an electric current, but it is associated, like the contraction of muscles, with electric currents and may be of electrolytic nature. The molecular change certainly involves the breaking down of protein matter, in the course of which there is a production of carbon-dioxide and lactic acid; but waste products are very scanty in amount, and nerve tissue seems to breakdown only to an infinitesimal extent as a result of its impulsive processes. Nevertheless, the chemico-physical constitution of nerve matter must be extraordinarily unstable, since the slightest stimulus suffices to set up great disturbance. The slightest touch of the end of a fine hair is instantly felt in the brain, meaning that the touch has set up a disturbance in the constitution of the end of the nerve fibre on the hand that instantly spreads upward along the whole length of the fibre to the brain. So, too, if we tickle the foot ever so lightly with a fine feather, the molecular disturbance runs right up to the spinal cord and brain, and results in afferent disturbances that lead to contraction of the muscles of the foot; and if the tickling be persisted in, it may lead to actual convulsions. So, again, a tooth

cutting the gum, or a grain of strychnine in the blood, may lead to great nerve explosions and violent contractions of the muscle. It is strange to find such constitutional instability and yet such precise functions.

For long it was thought that an impulse passed along a nerve at lightning rate, and physiologists despaired of ever succeeding in measuring its velocity; but, eventually, Professor Hermann von Helmholtz succeeded in timing the rate of impulse along the motor nerve of a frog, and discovered that it was only 90 feet a second. Many measurements have been made since then, and we now know that the rate of impulse varies in various animals. In man it is 300 or 400 feet a second. In an octopus it is from 9 to 15 feet a second, in the cuttle-fish only 2½ inches a second; but the rate varies in individuals and according to circumstances. Thus, if a frog be warmed up to 98° Fahrenheit, the rate of its nerve impulses is greatly increased.

It is possible that in nerve-cells there is a particular substance which is the basis of its explosive energy. Professor Nissl, of Heidelberg, has shown that all nerve-cells contain special little granules which have been called after him Nissl granules. They can be stained blue with methylene blue, and have quite a characteristic appearance. We find that in healthy nerve-cells that are fresh and fit, these granules are numerous, well formed, and well defined, whereas in any cell that has been stimulated to fatigue-point, the granules are less numerous and much less distinct and definite. These granules seem to be produced in some way by the nucleus

of the cell, and, like the nucleus, they contain a large percentage of phosphorus. It is not proved that they have anything to do with nerve energy, but it seems quite probable that they have.

We saw, when talking of muscular fatigue, that fatigue consequent on muscular work usually began in the nerve-cells of the central nervous system owing to the circulation there of waste products due to muscular contraction, and, of course, it is quite possible that the waste products may prevent the formation or utilisation of the granules.

There are many people who suffer from neurasthenia or nervous exhaustion, and many more people who fancy they do. The impulse of an afferent nerve ends in a disturbance and breakdown of the substance of the recipient nerve-cell: the impulse of an efferent nerve begins by a disturbance and breakdown of the substance of the efferent nerve-cell. As a rule the breakdown is quickly followed by restoration; but sometimes, when the nerve-cells have been exploded too violently or too frequently, they fail quite to recover, and the physiological processes dependent upon their potential energy become less efficient and more quickly followed by fatigue. In some cases there seems to be a natural lack of recuperative power in the nervous system, and any little excess of mental or physical activity leads to great and lasting impairment of energy; in other cases, exhaustion may follow upon extreme and prolonged mental or physical activity in a really strong nervous constitution. When the weakness is innate, when the explosive capacity of the nerve-cells has always been limited, probably little can be done in the way

of restitution; and sometimes, even when the exhaustion has occurred in a naturally energetic nervous system, the impairment of function may be permanent; but, as a rule, unless age or disease be at the back of the condition, the nervous system can be restored by rest, and food, and fresh air; and the Weir Mitchell treatment, which treats patients on that principle, is usually very successful. The nerve tissues and the Nissl granules contain a large percentage of phosphorus, and it is possible that food, such as milk and eggs, may aid in the restoration of fatigued nerve-cells; but, on the other hand, as you may lead a horse to the water but cannot make him drink, so one may lead a nerve-cell to phosphorus but cannot make it feed—in fact, its fatigue in many cases amounts just to an inability to build itself up or to feed. If fatigue be due simply to lack of food it is, as we know, very easily and quickly abolished. In any case, the modern indulgence in patent nerve foods and nerve tonics is much more likely to do harm than good. Nature made the nerve-cells without any patent food and tonics, and if they be mendable she can mend them without such useless assistance.

The nerve-fibres themselves are very difficult to fatigue. When nerve-cells and nerve-plates and muscles are fatigued, the nerve-fibres remain quite fresh.

If some people suffer from nerve debility, others suffer from nerve irritability. In some cases irritability is simply a symptom of debility, in other cases it is due to an inherent or acquired instability. Thus, if a gun goes off suddenly in the middle of

a crowd of men and women, some will hardly move, others will jump lightly, and others will be shaken and frightened. Those who are most moved will probably be suffering from nerve weakness, but others who are quite energetic and strong will also be considerably moved. The latter class we call highly strung, which simply means that the nerve-cells respond quickly and vigorously to stimuli, and nervousness of this kind is not pathological, and is often associated with great physical and mental energy and activity.

Hysteria is a disorder of the nerves in which afferent and efferent impulses seem to flow and overflow in wrong directions, and to cause nerve-cell explosions in the wrong places and in the wrong proportions. It is usually associated with general ill-health.

Besides such functional disorders as neurasthenia, nervous irritability, and hysteria, the nervous system is also subject to accidents and diseases which may completely destroy its wonderful mechanism. But we have not space to deal with these here.

Despite disorders and diseases, the nervous system remains the most marvellous thing in the whole world.

CHAPTER VIII

THE BRAIN

'There is but one temple in the universe, and that is the Body of Man. Nothing is holier than that high form. Bending before man is a reverence done to this Revelation in the Flesh. We touch heaven when we lay our hand on a human body.'—NOVALIS.

In dealing with the central nervous system we have necessarily and naturally made reference to the functions of the cells in the brain; but the brain is a big subject and demands a chapter to itself.

Nowadays the brain, as conceived by science, is well known to be the organ of thought and consciousness; we seem to be aware that our brains are at work when we think, so much so, that mind and brains are often used synonymously. But strange to say, the idea that the brain is the organ of thought is an idea of comparatively modern growth. In the Bible the word brain is never used, and quite other organs are regarded as the seats of thoughts and emotions. Thus we read: 'His bowels yearned with compassion,' and 'His reins instruct him in the night seasons,' and 'The Lord trieth the heart and the kidneys.'

The early Greeks had only an inkling of the idea. Plato and Alcmaeon taught that the brain was the temple of the mind; but Aristotle believed it was merely a wet sponge to cool the hot heart. Not till

experimental physiology began to be studied in Alexandria did man begin to realise the importance of the brain as an organ of thought, and not till the time of Galen were the intellectual and sensory functions of the brain fully established. Now, we know that the little handful of nerves and nerve-cells in the little skull-box is verily the hub of the universe. Now, science asserts that not only does the brain correlate various afferent and efferent impulses, so as to initiate and regulate the performance of various physical and chemical functions, but that it is the seat of volition, and that in it all man's sensations and emotions, and thoughts, are generated and elaborated.

When the brain is removed from the skull it looks not unlike a huge sweetbread—a pink, flabby, doughy-like lump of substance. It consists of at least three very obvious parts, the two halves of the cerebrum and the cerebellum, and its surface is much furrowed and fissured, so that it is divided into convoluted folds known as convolutions. Towards its base various nerves enter, and it is continuous below with the spinal cord. Within the cranium it is wrapped up in several coverings, and it is richly supplied with blood-vessels. When we cut into it and examine it microscopically we find that it consists of an outer, darker layer, known as the *grey layer*, formed mainly of millions and millions of nerve-cells, and an inner section composed of fibres coming from all directions. Chemically it consists mainly of ninety or ninety-five per cent. of water and some highly phosphorised fats, and it weighs on the average a little more than three pounds. There is nothing about it to show that it is anything special,

and yet, scientifically speaking, these three pounds of flabby, floppy stuff are the greatest dynamical machine in the universe.

So complicated is the brain that the labours of countless of physiologists have not yet succeeded in unravelling its fibres and disentangling the functions of its cells, but year after year more and more is being discovered.

When we make a comparative study of brains, we notice that the brains of the lower animals are smooth, and that, as we ascend in the animal scale of intelligence, furrows and fissures become more numerous and better marked, until, in the higher apes, we reach brains whose convolutions very much resemble the convolutions of the human brain. In the human fœtus the brain is also smooth, but, as it develops, the convolutions appear. Also, if we compare men and races of different degrees of intelligence, we find that the more intelligent have more convoluted brains. There is, therefore, obviously some connection between intelligence and convolution. We find, also, that as we ascend in the scale of intelligence the weight of the brain in proportion to the weight of the body steadily increases. To this rule, however, there are many exceptions, as the following tables will show:—

Average human brain 1360 grammes.

Dr Dollinger	1207	Agassiz	1512
Harley	1238	Thackeray	1644
Gambetta	1294	Schiller	1781
Liebig	1352	Cuvier	1829
Bischoff	1452	Tourgenieff	2012
Broca	1492	Byron	2238

Average human brain 48 ounces.

Abercrombie	64·7	Whewell	51·2
Lord Campbell	56·7	Grote	52
Webster	55·5	Tiedman	47·4
Chalmers	54·8	Hauseman	45·4
De Morny	54·0	Helmholtz	45

We see, by these tables, that Byron's brains were almost twice as heavy as Gambetta's, and that Abercrombie's brains weighed 50 per cent. more than Helmholtz's; but no one could believe that these differences in weight corresponded with differences in intellect.

But these tables, of course, do not take into account the size of the man, and, quite apart from intelligence, the large man requires a large brain for general purposes of correlation, etc. Hatters tell us that in Aberdeenshire, Yorkshire, and Ayrshire, where men are biggest, hats are largest.

Karl Pearson and Dr Raymond Pearl analysed the weights of 2100 adult male and 1034 adult female brains of Swedes, Bavarians, Hessians, Bohemians, and English, and reported as follows in the *Journal* of the Biometrical Society. 'There is no evidence that brain-weight is sensibly correlated with intellectual ability. Of the five races investigated by the biometricians, the English have the smallest mean brain-weight. The mean of the adult Englishman is 27 grammes less than the Bavarian mean, 65 grammes less than the Swedish mean, and 120 grammes less than the Bohemian mean.'

On the whole, then, we are inclined to believe that though working up through the animal species

there is a steady increase of brain-weight with increase of intelligence, yet, when we reach man, weight is of comparatively little importance, since the development of brain has become more a matter of increasing physiological efficiency and of increasing structural intricacy in special parts than of increasing bulk. After all, only a small part of the brain is concerned with intellectual functions; and the efficiency of these parts must depend more on the total extent of the convoluted surface of the brain, on the biochemistry of the cells, and on their afferent and efferent relationships, than on their size. We do find, of course, that heads below a certain size mean idiocy, but the small brain in that case is part of a general condition of arrested development.

Nor is shape of the skull of much value as a criterion of brain-power. Certain races, as we know, deform their skulls by boards and bandages, and yet their intellect is unimpaired; and we find that different races have different shapes of head without corresponding differences in mental capacity. In England, for instance, the head is generally long and narrow, and in Central Germany and France the head is short and wide,—but it would be impossible to account by differences of that kind for intellectual difference.

One of the most interesting things about the human brain is the great increase in size after birth. When the human baby is born its brain weighs only about 300 grammes—only about the same as the brain of a gorilla, or orang-outang, or chimpanzee, at birth. But the human brain grows till it is five times its weight at birth, whereas the

brain of the anthropoid shows only a fractional increase after birth. This is pre-eminently a human characteristic and is related to the educability of the brain.

In the beginning of the last century a Dr Gall came to the conclusion that separate areas in the brain were devoted to various faculties and capacities, that they could be located, and that their development could be judged by the hollows and bumps on the outside of the skull. By a comparative study of skulls and characters he claimed to have located various intellectual and emotional organs, and he drew out a chart of the skull with sixty little plots representing amativeness, and eloquence, and hope, and courage, and generosity, and combativeness, and so on. Thus he founded the so-called science of phrenology, which has a certain number of professors, even in the present day, who claim to be able to read a man's character by feeling his 'bumps.'

As a matter of fact there is little correspondence, certainly no precise correspondence, between the elevations and depressions of the skull, and the elevations and depressions of the brain convolutions, and the divisions suggested by Gall were neither scientific nor philosophic; but, nevertheless, there was a substratum of truth in his idea. In a rough way, though we cannot divide up the higher mental faculties as Gall suggested, yet they seem to be located in certain areas of the brain; and within the last twenty years various faculties and capacities have been precisely located by scientific methods of experiment and reasoning.

In 1861 a French physician, named Broca, noticed

that patients who had 'a shock,' and who lost power of speech, and who afterwards died, were always found on post-mortem examination to have had hæmorrhage in a convolution, known as third left frontal convolution or Broca's convolution, in the left frontal region of the brain. He, accordingly, came to the conclusion that this area was the motor centre of speech. Three years later, Hughlings Jackson pointed out that in certain cases of epilepsy damage was always to be found in certain convolutions of the brain. A little later, Fritsch and Hitzig found that it was possible to produce various co-ordinated movements in the limbs of dogs by stimulating certain areas in the frontal region of the brain. Soon numerous experiments were made on the higher apes and man, and various functions were located and mapped out.

Now we know exactly where are the motor-cells of the toes, ankle, knee, hip, shoulder, fingers, thumb, arm, leg, eyelid, jaw, and other parts of the body, and we have found among other things that the left side of the brain controls the right side of the body and *vice versa*. We also know where various centres of sensation are situated. We know where the wonderful cells are situated—strangely enough at the back of brain which mean sight to us, and where the cells of hearing, and smell, and touch, and taste, have their abode. It is true that in man such a thing as a simple sensation is impossible. The moment we see a golf-ball, for instance, we have in our consciousness at once the knowledge of its solidity, of its size, of its shape, of its uses, of its position in relation to other objects, and the total concept may be result

of many nerve centres in different and distant areas. Yet, in any concept, some special sense impression will be dominant, and there are certain cells in the brain which are most closely and intimately connected with the various senses, even though their activity at once rouses into activity associated cell-areas.

The most wonderful feature of the brain is its power of storing up memories that modify its response to afferent impulses. If I give a normal dog a bone containing cayenne pepper he will avoid or suspect bones in future which I offer him, whereas a dog without cerebral hemispheres would eat the bone every time.

By way of experiment, the whole cerebrum of an animal has been often removed. The result has been found to vary with the animal, and the higher the animal the more serious has the result been.

If the cerebral hemispheres are removed from a bony fish, the fish does not seem to be much affected. The principle afferent impulses that regulate its activities come through its eyes, and the eyes and centres of sight are not damaged in a fish by removal of its cerebrum. Without a cerebrum its eyes can still distinguish a worm, and it can swallow the worm quite successfully. Removal of a shark's cerebrum, on the other hand, renders the shark quite useless, for with the cerebrum is removed its olfactory tracts, and it is smell that controls and initiates the movements of the shark. A frog without a cerebrum can catch insects, can swim, and crawl, and perform other co-ordinated movements with its limbs. A bird without a cerebrum remains sleepy and motionless

unless disturbed. If thrown into the air it flies, and the eye reflexes direct it to settle on a perch; but it has no initiative. A dog without a cerebrum becomes simply a reflex machine without memory or emotions. In man, hundreds of thousands of fibres pass between the cerebrum and the spinal motor centres, and complete removal of the cerebrum would doubtless cause complete paralysis.

One of the most fatal and distressing diseases to which man is subject is cerebral hæmorrhage—hæmorrhage into the tissues of the cerebrum. The result is paralysis. In some cases the face is paralysed on one side of the body, and the arm and leg on the other side of the body. In other cases, a single limb may be affected. But in every case where there is any considerable hæmorrhage there will be paralysis. When, on the other hand, tumours or fragments of depressed bone press upon the cerebrum, they cause symptoms of stimulation. Thus, if a tumour press upon the area in the cerebrum which has motor centres for the thumb, twitches will be caused in the thumb, and, possibly, general epileptiform convulsions. In such cases the twitching muscles tell the surgeon on what part of the brain the tumour is pressing, and he is often able to cut down and remove the tumour, a happy consummation that we owe to vivisection, for without experiments on monkeys it would have been impossible to localise the motor areas of the brain. Some of the operations performed by the great brain surgeons have been very sensational and wonderful.

There are many parts of the cerebrum of whose function we know nothing. We know nothing, for

instance, of the convolutions immediately behind the forehead. These are specially developed in men and in clever men, and they have often been supposed to be the seat of some of the higher faculties, and they probably are, but there is little proof of that. One case is known where the frontal convolutions were destroyed. A crowbar was forced by a dynamite explosion right through the roof of the orbit of an eye and came out through the man's brow, carrying away the front part of his brains. The man, a foreman, recovered and went back to his work with his mental faculties apparently quite unimpaired, but he degenerated in moral character, took to drink and became untrustworthy. It would be rash to infer too much from a case like that.

It is quite possible that some parts of the brain are still in embryo, and have to do with new mental and spiritual faculties yet to be developed in the race.

In a Lumleian lecture, Dr Baddeley gives the case of a boy who lost a portion of his brain through a fissure in his skull caused by an accident, and so little was the boy upset by the injury that he earnestly begged that the part of his brain might be sent to his schoolmaster, who had frequently asserted that he had no brains.

The *Anthropological Review* gives a similar case: 'A young man at Ghent lost, by a pistol-shot, two teacupfuls of brain, and more at subsequent dressings. He lived for two years with his intellect vastly improved, having been before of limited intelligence.'

Again, it is stated in the *Opuscules of Chirurgie* (Paris, 1806) that Paroisse received, after the battle of Landrecies, in the hospital at Soissons, twenty-two wounded soldiers. In all of them a considerable

portion of the cranium, integuments, and brain had been cleanly cut off in battle by sharp swords. All of them marched with their wounds thirty-five leagues, about five leagues a day, to the hospital. Ten of these soldiers, in whom the loss of bone, integument and brain was less, recovered completely within seven weeks. The remaining twelve were carried off in about three weeks. In none of these were the intellectual faculties much disturbed.

Many more such cases may be quoted, and the inference is quite legitimate that parts of brain are as yet in embryo, and are not yet essential and active parts of the nervous system. Still, the cerebrum as a whole must be considered the seat of intellect. From the point of view of science, the network of cells and fibres which compose it, is the basis of the association of ideas and the volitional initiation of movements. We say the volitional initiation of movements, for the cerebral cells do not actually correlate the various muscles that perform any function, such correlation is left to the cerebellum and spinal cord, and the various afferent impulses that reach these. The wish is a vibration, or causes a vibration, of certain cerebral cells, and this vibration propagated to subsidiary centres of the nervous system induces them to gratify the wish by vibrations in themselves propagated to the muscles, and regulated again by afferent discharges from the muscles, joints, skin, inner ear, and other parts participating in the movement, or affected by it.

The cerebellum, which is at the back of the base of the cerebrum, is particularly the centre for the co-ordination of various muscular movements.

Disease of the cerebellum in man, or removal of

the cerebellum in animals, produces muscular weakness and a staggering unsteady gait. The motor-cells cerebellum, that assist in the preservation of equilibrium, are stimulated to due action by afferent impulses. Such afferent impulses are sent from the skin and eyes, but chiefly from the muscles and joints and semicircular canal. The semicircular canals consist essentially of three semicircular tubes set in three different planes in the internal ear and filled with fluid. They are so constituted that the movements of the fluid within them, as they change position with movements of the head and body, excite afferent nerves. These afferent nerves send impulses to the cells of the cerebellum, and the result is efferent impulses from the cerebellum to the muscles concerned with equilibrium. Injury or disease of the semicircular canals cause great disturbance of equilibrium.

Certainly one of the most important functions of the cerebellum is the interpretation of afferent impulses which reach it from the semicircular canals, and the co-ordination of muscles to preserve equilibrium under the circumstances so indicated.

One of the most interesting and suggestive things about the brain is the fact that it has four times as many afferent as efferent fibres, and that the same efferent nerve-cell and efferent fibre may receive various afferent impulses and send various efferent messages. Judging from the proportion that exists between efferent cells and afferent nerves, each efferent nerve-cell may receive four different impulses along four different afferent nerves. In every case it will respond according to its inherent character and constitution. But there will be various differences

in its response to the various stimuli. Now supposing that two afferent stimuli reach it from two different nerves at the same time, to which stimulus is it to respond? Here it is possible that the element of volition comes in, and that either the will in some mysterious fashion has the power of choosing, or that the conflict between the two stimuli, ending in the victory of one of them, gives rise in consciousness to that conscious experience which we call effort of will.

The most wonderful afferent nerves are, of course, the nerves of sight associated with the eye, and the nerves of hearing associated with the ear.

The eye consists essentially of a sensitive receiving surface, the retina, which responds by chemico-physical disturbances to the impact of waves of light, and sends impulses up the optic nerve to the cells of vision in the brain. The retina is spread over the interior of a little hollow ball, the eyeball, which is made chiefly of very tough, strong fibrous tissue, white and opaque, but has a window of transparent tissue like the glass of a watch, the cornea, in front, through which the rays of light reach the retina. Behind the window is a little transparent biconvex lens which focuses the light on the retina. The lens is carried in a little transparent circular bag which can be tightened at need by little muscles, the *ciliary* muscles, in such a way as to compress it and lessen its convexity, and in this way it is adjusted to focus light from objects near and far. In addition, there is a circular muscular curtain, coloured black, or grey, or brown, or blue, round the margin of the lens, between the lens and the light, which limits the entry of the

light to the round window or pupil it leaves, and by contracting and relaxing diminishes or increases the amount of light falling upon the retina. It is, in fact, like the diaphragm used in photographic apparatus. In darkness or dim light the pupil expands, in bright light the pupil contracts. In the interior of the eyeball is a jelly-like substance known as the vitreous humour. The eyeball is set in a bony socket, and is moved in various directions by muscles attached to it. It is guarded by the eyelids and kept moist and clean by the water from the lachrymal gland, which is conveyed away from the eyeball into the nose by a special duct and gland. This is only a brief, bald, inadequate description of some of the main features of the structure and plan of the eye; but they will suffice to give the reader some idea of the ingenuity and complexity of the organ.

The retina is in itself a most intricate and complex structure, but the scientific formulation and interpretation of material phenomena always lead to purpose, and every cell of it, be sure, will be found to have a purpose, and to have had a purpose from the first.

It is really a portion of brain substance, and its tissue consists chiefly of innumerable cells and fibres. Though it is only $\frac{1}{120}$ of an inch thick, no less than twelve layers are distinguishable. The deepest layer—the layer, that is to say, next the optic nerve—is made up of cells like rods and cones standing close together side by side, and, therefore, is sometimes known as the layer of rods and cones. These rods and cones are the remarkable cells that transmit to the optic nerve the

impulses evoked in them by the waves of light—impulses that finally appear in consciousness as light, and colour, and other visual sensations. The rods contain a purple pigment known as *visual purple*, and this pigment, no doubt, plays its part in the chemical processes of the nerve-cell impulse. It is bleached by exposure to light, but is quickly reformed. The visual purple, being sensitive to light, renders the retina a kind of photographic film, and photographs ('optograms') of a kind can be taken on it and fixed. 'A rabbit's eye is cut out and placed in front of a window. After some time the eye is bisected and plunged into a 4 per cent. solution of alum which partially fixes the optogram, and an inverted picture of the window with its cross-bars is obtained on the retina.' But it must not be thought, therefore, that the sensational stories that one sometimes reads of murderers' photograms found on their victims' retinæ have any foundation in fact. There are estimated to be three million rods and even a greater number of cones in the retina of man, and there are said to be five hundred thousand fibres in the optic nerve. The Darwinians profess to believe that all these millions of cells and fibres, correlated in such innumerable and effective ways as to produce in us the multitudinous vision of the world, are the result of selective action of environment on chance shots by Nature. What an extraordinary chance it was that Nature found even a single cell to give visual consciousness when played upon by invisible waves of ether!

Our reason leads us to believe that waves of energy radiate from the sun and flash across space

at a rate of about two hundred thousand miles a second; and that some of these set up impulses in the optic nervous system that appear in consciousness as visual sensations—some colour sensations, some colourless sensations. The colour sensations in normal eyes comprise all the colours of the spectrum; but there are about five per cent. colour-blind people who are blind to certain colours.

Colour vision was analysed by Thomas Young and Helmholtz into three primary sensations of red, green, and violet. They showed that sensations white and all other colours could be produced by blending these in right proportions. And, starting from this principle, they elaborated the trichromatic theory of colour vision. They suggested that there were three different kinds of cones in the retina, one kind producing the sensation red when stimulated, another kind producing the sensation violet, and a third kind the sensation blue; and that when all three kinds were equally stimulated, white was the result in consciousness, while the other colours depended on the proportions in which the three kinds of rods were excited.

Another theory of colour vision suggests that there are six primary colours—black, white, red, green, yellow, blue. But neither theory is quite satisfactory.

The lens, as we mentioned, is for the purpose of focussing upon the retina the light from near or far objects. In the normal eye the lens, when the ciliary muscle of the eye is at rest, focuses the light from distant objects; but in order to see near objects distinctly, the ciliary muscle must contract and render the lens more convex. This adaptation

is called accommodation, and is a purely reflex movement.

Short-sightedness is due to too great elongation of the eyeball, so that rays of light from distant objects are focused in front of the retina.

Long-sightedness is due either to insufficient length of the eyeball, so that the rays of light from near objects are focused beyond the retina, or, in the case of old age, to a loss of elasticity in the lens.

Astigmatism, or inability to focus at the same time horizontal and vertical lines at the same distance, is due to a greater curvature of the cornea or lens in one meridian than another. All these defects can be remedied by suitable artificial lenses.

The organ of hearing is almost as wonderful as the organ of seeing, and its mechanism is fully as difficult to understand. It consists essentially of an extension of the nerve of hearing, and an elaborate apparatus to transmit to it certain vibrations of the air. We can divide it into three parts—an outer, a middle, and an inner ear. The outer ear consists of the leaf-like *external organ* so-called, which serves to collect the sound waves, and a tube an inch long leading to a delicate vibratile membrane. Within the delicate membrane, or *membrana tympani,* is the inner ear, a bony cavity communicating with cellular cavities in the thick bone (the mastoid process of the temporal bone) in which it lies, and containing three tiny bones forming a kind of chain across the cavity attached, on the one hand, to the membrana tympani, and, on the other hand, to another membrane applied over an opening in a

coiled, bony tube like a snail's shell, called the *labyrinth,* which contains a fluid in which are immersed the terminations of the auditory nerve. The vibrations of the membrana tympani are transmitted across the inner ear by the ossicles, and set the second membrane into vibration, and its vibration again causes changes in the pressure of the fluid in which the nerve of hearing is immersed.

The little chain of little bones which transmits the vibrations of the membrana tympani tends both to transmit the vibrations to the second membrane and to prevent the membrane from vibrating at a rate determined by its own tension and structure, and this is further secured by a little muscle, the *tensor tympani*, which pulls on the bone attached to the membrana tympani, and thus tightens the membrane. Moreover, the bones are arranged in such a way that leverage comes into play, and the final bone exerts on the second membrane a force thirty times as great as the force of the vibration of the first membrane. But though the force is greater the motion of the second membrane is proportionately less, and its vibrations accordingly are very small. But so sensitive is the central apparatus of hearing that we can hear, so it is calculated, waves of air less than $\frac{1}{60000}$ of an inch in length. The final contrivance whereby the vibrations are imparted to the afferent fibres of the auditory nerve is very complicated and not fully understood; but the final result is the marvellous faculty of hearing which we possess.

According to embryologists and biologists, the external opening of the ear is a development of the first gill-cleft of a fish, and two of the three

little bones which convey the vibrations of the membranous drum were, at one stage of the evolution of man, a part of the lower jaw and a bone at the base of the skull with which the lower jaw was articulated. When mastication and molar teeth were evolved, then the two little bones were taken into the service of the ear.

These wonderful afferent impulses, spreading up the afferent fibres of the nerves of the ear and eye, and resulting in consciousness of light and sound, impress upon us the mystery of mind and body. Molecular movement is not light; molecular movement is not sound: we may magnify them till the molecules are the size of planets, they will never become redness, or blueness, or loudness, or music. Yet we believe that the moment that certain molecules in certain cells in our brain begin to be shaken in certain ways, light and sound enter consciousness. And the light and sound only enter the consciousness of the man in whose body the cells are. Certain cells in a man's brain vibrate, and his consciousness is full of sunlight and song; but supposing I could behold every movement of those molecules, suppose I could touch them and feel them vibrate, they would not mean sunlight and song for me. What is the connection that makes the vibrations become the source of something that seems not to be in them? The waves of ether have no colour, the molecules have no colour, and the waves of the air are silent: the molecules make no sound.

It is a riddle that none can solve. We study the body patiently and faithfully, we analyse it to the utmost, we try to get to the bottom of it in ten thousand ingenious ways, and, at the very farthest

point we can attain we find ourselves bewildered and lost in pitch darkness.

Tyndall, in his famous Belfast address, imagines Bishop Butler arguing thus: 'I can follow the waves of sound until their tremors reach the water of the labyrinth and set the otoliths and Corte's fibres in motion; I can also visualise the waves of ether as they cross the eye and hit the retina. Nay, more; I am able to pursue to the central organ the motion thus imparted at the periphery, and to see in idea the very molecules of the brain thrown into tremors. My insight is not baffled by these physical processes. What baffles and bewilders me is the notion that from these physical tremors things so utterly incongruous with them as sensation, thought, emotion, can be derived. You may say or think that this issue of consciousness from the clash of atoms is not more incongruous than the flash of light from the union of oxygen and hydrogen, but I beg to say that it is. For such incongruity as the flash possesses is that which I now force upon your attention. The flash is an affair of consciousness, the objective counterpart of which is a vibration. It is a flash only by your interpretation. *You* are the cause of the apparent incongruity, and *you* are the thing that puzzles me.'

The fact is that, from the first, science is standing in a bucket and trying to raise herself by the handle. Science begins by supposing that it is outside the matter it studies, and analyses, and goes on quite merrily till it finds that the matter cannot account for sight and sound. But matter, even considered as particles in motion, is not a thing outside consciousness and cannot be considered as purely objective. We talk about vibrating particles, but vibration, and

particles, just as much as sight and sound, are not properties of some mysterious something outside our perception, but elements of consciousness and most abstract conceptions. It is true that by the dualistic assumption of mind and matter we reach various conclusions of pragmatic value; but the assumption from the first is false, and must eventually lead to a *reductio ad absurdum*. Consciousness is a great mystery that we cannot get behind, and all these hordes of cells, and mazes of fibres, and vibrating molecules are items of consciousness—of the very consciousness that we think we are going to find a cause for.

The only cause for mind and for the world in mind that we can discover is Mind, and, if we choose to give the Mind Personality or self-consciousness such as we ourselves have, it is at least a working hypothesis and as good a symbol of the truth as we are likely to get.

In a provisional symbolic way we may look on the brain as the organ of the mind with wonder and admiration; but if we look a little deeper we recognise that the brain and all its contents are merely particular parts of the mind that holds them, and that apart from the mind have no more existence than the light that shows us their intricacy and the idea of intricacy itself. The scientific view, however, is true within limits, and even from the provisional scientific analysis of the body, we get some idea of a great Purpose at work.

CHAPTER IX

THE HEART

We have described some of the marvels of muscle, but there still remains to describe the most wonderful muscle of all—the little crimson bag of throbbing fibres known as the heart. All life long it grips and slackens, slackens and grips. All life long it drives the red blood through millions of tubes and tubules. It weighs only about half a pound: it is not larger than a man's fist; but the work it does is tremendous.

An active man can raise himself 2000 feet in an hour: the heart does work equivalent to raising itself 6000 feet in an hour. In twenty-four hours it does sufficient work to raise itself about thirty-five times to the top of Ben Nevis. Put otherwise, in twenty-four hours it raises 32 tons, or 144,600 times its own weight, a foot high. That is what it does on the average, day in and day out; but in times of strain and stress it may do three times as much. And so quietly and so steadily does it work that one is hardly aware it is working at all.

It begins to work when it is hardly made, when it is microscopically small. Harvey, who discovered how the heart pumps the blood, tells how he saw the new-born heart beating in the embryo chick. 'I have also observed,' he says, 'the first rudiments of the chick in the course of the fourth or fifth day of incubation, in the guise of a little cloud, the shell

having been removed and the egg immersed in clear tepid water. In the midst of the cloudlet in question there was a little bloody point, so small that it disappeared during the contraction and escaped the sight, but in the relaxation it reappeared again, red and like the point of a pin; so that betwixt the visible and invisible, betwixt being and not being, as it were, it gave by its pulses a kind of representation of the commencement of life.'

A little bloody point, like the point of a pin, glowing like a red star in a cloud, blossoming and fading away, that is how the proud heart of man begins, but no movement in the universe, not the whirling of a sun, not the bourgeoning of a nebula, is so wonderful as the rhythmical systole and diastole of this tiny red beadlet, for it is the beginning of the activities of life. There is no brain then to feed, there are no lungs to supply the blood with oxygen, but this little beadlet knows what is to be, and begins to beat.

From earliest times the haruspices that practised divination from entrails, the dissectors, and the embalmers, must have been acquainted with this purple pouch. We can hardly imagine the conception of a man without a heart. Still, for centuries man knew very little of his heart's purpose, structure, and mechanism. Aristotle thought that the heart was the central heating furnace of the body, and that the arteries were filled with air which they brought to the heart to keep it from becoming too hot. He also thought that the food digested in the stomach went to the heart, and was mixed with vital spirits and made into blood. The

expansion of the heart he thought to be due to the expansion of the food under the influence of the heart's heat. His conception of circulation was an ebb and flow of blood to the heart produced by the heart's suction. Galen developed the doctrine of spirits, and thought that it was the vital spirit produced by the mixture of blood and air that moved the heart. He, too, thought the heart moved the blood by suction.

Descartes was under the dominion of similar beliefs: he thought the heart's heat made the blood expand, and that the expanding blood expanded the heart. All anatomists and thinkers too were under the impression that the blood flowed in the veins in a direction from the heart.

Our language and literature are full of interesting references to these early beliefs. Thus, Milton says that when Eve ate the apple she had 'ampler spirit and dilated heart.' And Shakespeare, thinking no doubt of the ebb and flow and suction theory, writes, 'Dear to me as are the ruddy drops that visit this sad heart.' The very terms 'high spirits' and 'low spirits' are reminiscent of the old imaginative physiology.

The idea that the blood circulated, and that the heart pumped the blood round the body, was of very late growth. Galen had suggested that the blood which went to the lungs was sucked back to the heart again, and in the sixteenth century Servetus, who was burnt at the stake by Calvin, and his contemporaries, Winter and Columbus, promulgated the same doctrine. But not till 1571, when Andreas Cæsalpinus, a naturalist theologian and physician of Pisa, published his *Questiones*

Peripateticæ, did any scientist or thinker realise that the heart acted as a force-pump, that it drove the blood round the body, and that its valves were an essential part of the mechanism of circulation.

By dint of logical reasoning Andreas Cæsalpinus certainly did reach these conclusions, but not till fifty years later was the truth of his reasoning practically demonstrated.

Harvey it was who worked out practically the mechanism of the heart's action. He had taken the degree of Doctor of Medicine at Padua, and probably had some knowledge of Columbus' and Cæsalpinus' theories: but he came to his conclusions by his own ways in the course of his own work.

He took his degree at Padua in 1602. In 1615 he was appointed Lumleian lecturer, and had 'to dissect openly in the reading-place all the body of man, especially the inward parts, for five days together, as well before as after dinner, if the bodies may last so long without annoy.' It was in the course of this work that he reached the truth, and not without hard labour did he reach it. He dissected not only man and the larger animals: he dissected also frogs and lizards, and doves, and oysters, and tortoises, and snails, and crabs, and slugs, and shrimps, and mussels, and serpents, and fishes, 'even wasps, and hornets, and flies.' As a result he demonstrated that 'it is absolutely necessary to conclude that the blood in the animal body is impelled in a circle and is in a state of ceaseless motion, that this is the act and function which the heart performs by means of its pulse, and that it is the sole and only end of the motion and contraction of the heart.'

It was a wonderful discovery to make, and the microscope soon came to confirm it. Four years after Harvey's death, Malpighi, a great Italian microscopist, discerned in the lung of the frog the fine tubules or capillaries which connect the fine branched endings of the arteries with the fine branched beginnings of the veins.

'There appears,' he wrote, 'a network made up of the continuations of the two vessels. This network not only occupies the whole area, but extends to the walls, and is attached to the out-going vessel. . . . Hence it was clear to the senses that the blood flowed along tortuous vessels and was not poured into spaces, but was always contained within tubules.'

A few years later the Dutch microscopist, Leeuwenhoek, saw the capillaries in the tails of tadpoles.

'I saw,' he declares, 'that not only the blood in many places was conveyed through exceedingly minute vessels from the middle of the tail towards the edges, but that each of the vessels had a curve, or turning, and carried the blood back towards the middle of the tail, in order to be conveyed back to the heart.'

It was one of the most remarkable discoveries in the history of mankind. This little purple pulsating purse was really an ingenious pump that forced the blood round and round the body. It was a wonderful thing that there should be this muscular bag beating in a man, and in all the hundreds of thousands of animals, in the world; but the thing grew far more wonderful when we discovered that it kept the red river of blood flowing round and round.

The writer remembers that when as a little boy he was told about it, he made no remark, but he did not *quite* believe it. And, really, it is almost too wonderful to be true; and after Harvey published his book 'he fell mightily in his practice, 'twas believed by the vulgar that he was crackbrained.'

Now let us look for a moment at the general structure of the heart and the arteries. The heart is rather like a pear in shape, and lies obliquely, point downwards, in the chest cavity between the right and left lung. It is contained in a fibrous bag called the 'pericardium,' which gives it room to expand and yet helps to restrain too great expansion. The inside of the bag and the outside of the heart are covered with a very smooth moist membrane, so that there is no friction between the heart and the bag when the heart expands and contracts.

On the outside of the heart under this membrane run the arteries that bring oxygen and food to it; for the heart, like every other muscle, requires food and oxygen.

When we open the heart, we find that it has four chambers—two at the base of the pear and two at the apex. The two at the base are called the right and left 'auricles,' and their part is to squeeze the blood into the two chambers at the apex which are known as right and left ventricles, and are much the most important part of the heart. The left ventricle may be considered the ruling spirit of the heart. When it contracts it drives the blood into a big artery known as the aorta, and through the aorta into all the arteries, big and little, of the body, and through the little arteries into the capillaries, and

through the capillaries into the little and big veins of the body, which finally end in two big veins that open into the right auricle. The right auricle squeezes the blood into the right ventricle, and the right ventricle drives the blood through the lungs into the left auricle, and the left auricle passes it on again to the left ventricle, and there the circulation starts afresh. The left ventricle is much more muscular than the right, and upon it most of the labour involves. It has to drive the blood right round the body through brain, and big toes, and kidneys, and liver, and every other part; while the right ventricle has to drive it only through the lungs. It must not be thought, however, that the left ventricle has no assistance. All the arteries are encircled with rings of muscles and elastic fibres, and these contract, help, and force the blood along. In the veins, too, there are weaker muscles that also assist, and the suction of the expanding right ventricle, and expanding chest, and the compression of contracting muscles, also help to move the blood onwards. One knows that one can make a valved bulb on a piece of elastic tubing, and by pressing the bulb cause a steady spray to come through a nozzle, and, in just the same way, the musclo-elastic tubing of the arteries makes the blood flow in a steady stream from ventricle to ventricle. Were the tubing not elastic the blood would flow in jerks. The orifice that leads from the left ventricle into the aorta is guarded by a valve of such a nature that it permits blood to flow into the aorta, but does not allow blood to flow back into the heart. When the left ventricle has driven its blood into the aorta the back pressure closes the valve, and its closure can be heard as a

click. The orifice that leads from the right ventricle into the big vessel that carries blood to the lungs is guarded by a valve which allows the blood to flow towards the lungs, but not back towards the heart. The orifices again, between the auricles and ventricles, are guarded by valves that allow the blood to flow from the auricles to the ventricles, but not in the reverse direction.

Thus when the heart contracts the blood can flow in one, and only in one, direction.

The valves have two or three cusps each, and are beautifully constructed for the purpose for which they are meant.

The cusps of the valves between the auricles and ventricles are strengthened by little tendinous strings that run between their margins and little nipple-like muscles in the walls of the ventricles. These strings pull on the edges of the cusps and prevent them from being turned inside out, like an umbrella in the wind, by the pressure of the blood in the contracting ventricles.

Altogether the heart is a very wonderful machine.

The first artery—the aorta—that leads from the heart is a big tube, but its branches, if all put together, would make a much bigger tube, and the capillaries, if made into one tube, would make a bigger tube still—a tube several hundred times the diameter of the aorta. The result of this is that, as the blood flows from heart to veins, its rapidity grows less and less. Thus in the capillaries its course is very sluggish, and the tissues have plenty of time to avail themselves of all the food and oxygen it brings. In the aorta it flows at a rate of about 60 feet per minute, and in the capillaries about an inch a minute.

The amount of blood that is forced out by the heart at each beat is about 4½ ounces. The shortest time taken for it in man to pass right round the body—through the carotid artery to the veins and back again to itself, for instance—is 15 seconds; but, of course, in some circuits blood takes longer than in others, and, on the average, any drop of blood will take about 45 seconds to go from the heart to the heart. Probably a drop of blood goes, on the average, nearly a mile a day, or 365 miles a year, or over 25,000 miles in a lifetime of 70 years. The routes a drop of blood can take in the capillaries are innumerable, for the capillaries in aggregate stretch for thousands of miles. The capillaries in the lung alone are enough to reach across the Atlantic. In the capillaries there is a constant leakage of blood with nutrient contents to the tissues, and a constant passage of waste material from the tissues to the blood, and the length of the capillaries is for the purpose of facilitating this interchange.

The beating of the heart is a function of the heart-muscle itself: it commences before there is any nervous system, and it can take place when all the nerves that go to the heart are severed. Yet, though the muscle of the heart has power of independent movement, and requires no nerve impulse to start it, nevertheless it is under nerve control and carefully regulated by the nervous system. At all times the natural muscular rhythm of the heart is slowed down by impulses from the nerves known as 'vagi' nerves. If these nerves are cut or poisoned by belladonna, the heart beats faster. If they are gently stimulated, the heart-beat is slowed. If

they are strongly stimulated, the heart stops altogether.

These are restraining nerves. But there are also accelerating nerves—certain branches of the sympathetic nervous system—which, as a rule, do not act but are brought into action when necessary.

The vagi nerves may be considered as reins; the sympathetic nerves as spurs. The reins are always more or less taut; but the spur is used only now and then. Both reins and spurs, however, be it understood, are outside the sphere of the will: they are under the jurisdiction of a nerve centre at the base of the brain. Through nerves that enter it, this centre is in constant communication with all parts of the body, and adapts the rate and strength of the heart-beat to the needs of the organism, with a wisdom of which our will would be quite incapable.

The heart of an adult man usually beats about seventy or seventy-five times a minute, and the heart of women and children rather faster; but there are great differences in rate of heart-beat compatible with health. Some men in perfect health have a heart-beat of eighty or ninety a minute, while others, such as the great Napoleon, have a heart-beat of only forty a minute.

The only rest the heart enjoys is the momentary pause between its beats. In that fraction of a second it has to build itself up and to lay in a store of energy. A very wonderful thing about the heart is its power of continuing to beat even when it has been cut out of the body.

If a frog's heart be cut out it will continue to beat for a few minutes or a few hours; while if it

be fed with a nutrient fluid, or its own blood, or the blood of an animal of the same species, it will continue to beat for days. The fluid must be warmed and oxygenated, and must be made to circulate in the vessels of the heart. The best artificial nutrient fluid is just a solution of salts, mainly common salt and sugar. By means of such an artificial nutrient fluid, not only the hearts of frogs but the hearts of mammals can be kept beating for days. Surely that is a wonderful sight—a heart outside the body throbbing and beating away by itself while the limbs and brain it used to serve are lying dead and rigid!

It used to be thought that a wound in the heart was inevitable death, but modern surgeons have, on more than one occasion, opened the chest wall and saved patients' lives by stitching up wounds in the heart. Recently, the great French-American scientist and surgeon Alexis Carrel, actually stopped the heart beating by tying its great arteries, then cut into it and scraped its valves, and then untied the arteries again, with restoration of the heart's movement and the circulation.

Such is the incorrigibility of the beating heart that even a strip of it will beat if it can only get food, and quite lately Carrel has kept strips of heart-muscle beating for months.

CHAPTER X

THE BLOOD

Almost more wonderful than the heart itself is the red fluid the heart propels. There are less than 10 pints of it in a man of average size, yet these few cupfuls of red fluid are pumped by the heart a distance of nearly 365 miles a year, and carry during that time some thousands of pounds of nutrient and some thousands of pounds of waste material.

When we analyse the red fluid we find that it consists of water with various little particles in suspension, and with various substances in solution.

Let us look first at the particles in suspension.

The particles in suspension are known as the blood-cells, and they are of two kinds, red blood-cells, and white blood-cells. The blood is simply swarming with these cells. In a drop of blood about the size of a large pinhead there are about 5,000,000 red cells, and 20,000 or 30,000 white cells.

Since the red cells are the more numerous, let us look at them first. They are tiny biconcave discs only $\frac{1}{3200}$ of an inch in diameter, and $\frac{1}{12000}$ in thickness. They probably consist of a sponge-like framework and a very thin outside membrane. There is no nucleus. Though they are called *red* cells, each individual cell appears yellow when viewed in the ordinary way through a microscope. It is only when seen *en masse* that they appear red.

The most remarkable thing about these cells is

their colouring matter. It is slightly different in the case of the cells in the veins, and the cells in the arteries; and the colouring matter in the former case is known as 'hæmoglobin,' and in the latter as 'oxyhæmoglobin,' since the latter contains more oxygen. On this little difference life depends. The cells exist simply to give and take oxygen. They take it from the air in the lungs as they flow through the lung capillaries, and they give it up again to the living tissues as they flow through the tissue capillaries. The difference in the amount of oxygen in the cells of the veins and the arteries is exhibited in the different colour of venous and arterial blood. The heart, the lungs, the vessels all exist mainly that these cells may obtain oxygen in the lungs, carry it to the tissues and surrender it there. They are the little red torches that light the fire of life, that join the oxygen of the air to the living compounds in the tissues, and thus convert potential into actual energy. Well may they be crimson.

It is, as we have said, the colouring matter, the hæmoglobin, that plays the part of the oxygen carrier and, chemically speaking, it is a remarkable compound, for it has the largest molecule of any known organic substance, and contains iron. There is no other organic substance of the living body that contains iron, and it is this iron, just one atom among hundreds of other atoms, that gives the blood its colour. Iron it is that makes a maiden's blushes and rosy lips. 'Is it not strange,' asks Ruskin, 'to find this stern and strong metal mingled so delicately in our human life that we cannot even blush without its help.'

All over the world, it is interesting to note, we see iron playing the part of painter in the compositions of life. It makes the grass green and the soil umber, orange, or russet: it tints agates, and jaspers, and cornelians, and onyxes, and cairngorms, and chrysoprases, and marble, and porphyry, and granite, and tiles.

Had Nature forgot to add a little iron to the crust of the earth there had been little colour and no life.

In very interesting relationship to hæmoglobin, the red colouring matter of blood, is chlorophyll, the green colouring matter of plants. Like hæmoglobin it owes its colour to the iron it contains, like hæmoglobin it has a large and complex molecule, and like hæmoglobin it is essential to life. Moreover, marvellous to relate, the green colouring matter in the plant, and the red colouring in the blood, work hand in hand in the economy of the universe. As we have already seen in a previous chapter, it is the chlorophyll of a plant that enables the sun to take the carbon from carbon-dioxide and set free oxygen; and it is the hæmoglobin of the blood that enables the tissues to obtain oxygen and set free carbon-dioxide.

When we realise the importance of the function performed by the red blood-cells, we begin to understand why there are such myriads of them. It is just in order that there may be a large surface to acquire oxygen, and millions of carriers to distribute it to every nook and cranny of the body. The cells are minute, since the smaller they are the more surface they present in proportion to their bulk—a cell $\frac{1}{3200}$ of an inch in diameter and flattened

like a disc is practically all surface together—and since it is necessary that they should be able to pass along the very minute capillaries.

We have mentioned that the capillaries in the lung alone are long enough to stretch across the Atlantic, and that altogether the capillaries stretch for thousands of miles; but the red blood-cells are more than sufficient to fill them. If all the cells were laid out flat, single-deep, edge to edge, they would cover an area of more than 3300 square yards, an area, that is to say, 1500 times the area of the whole surface of the body: they would form a pavement a foot wide and about 6 miles long; or a red tape half an inch wide and 140 miles long; while if they were arranged shoulder to shoulder in single file, they would stretch over 200,000 miles—more than two-thirds of the way to the moon. The whole surface of the world could be covered with the blood-cells of the human race.

Yet they are being constantly destroyed and replaced. Probably a red blood-cell does not last more than a fortnight, so that in the course of three-score years and ten enough red cells must be formed by each man to reach in single file more than three times to the sun. I have roughly worked out these figures on the basis of authentic physiological figures, but I confess they stagger me.

In what workshop are these cells turned out at the rate of millions a second? There seems no doubt at all that they are made in the red marrow of the bones. There their birth has been watched. They begin as little round nucleated cells, and as they get older they lose their nucleus. Who would

have imagined that the bones were capable of such energetic creation. Who would have guessed that all these red cells with their marvellous hæmoglobin were made inside the hard limy bones. Yet so it is, and it is enough to make us go down on our marrow-bones when we realise it.

The red cells are broken up chiefly in the liver, and the liver uses the iron of the hæmoglobin to colour its bile green and golden. One very remarkable fact about the red cells seems to have escaped notice. When they float in the blood they are certainly dying and probably dead cells. They have no nuclei: they do not respire: they do not multiply. The likelihood then is that our blood is filled with millions and millions of dead cells. It is to the dead then that we owe our life: millions and millions of cells die that we may live. Charon it is who steers the red barges down the stream of life. That is surely a startling thought.

If the red cells are dead, the white cells are very much alive. They have a nucleus: they move; no doubt they respire; and though they do not multiply in the blood, they multiply quite freely if they escape, as they often do, from the capillaries into the surrounding tissues. They are not nearly so numerous as the red cells but they are larger, averaging $\frac{1}{2500}$ of an inch in diameter.

There seem to be various kinds of white cells, for they stain in various ways and have variously-sized nuclei; but here we need not enter into these differences. They are all white cells; they have all nuclei; and they are all able to crawl or slither about. Their appearance and behaviour put them in the same class as the various amœboid

micro-organisms that live outside the body, such as the common amœba proteins found in ditch water. Strangely enough, too, many of the micro-organisms of this class are formidable enemies of man. The microbe of dysentery is an amœba: the microbe of sleeping-sickness is an amœba.

The blood, then, is full of these amœboid-like cells, and similar cells creep about in the connective tissue, or take part, as we have previously mentioned, in the building of bone.

Since there are millions and millions of these cells in the blood, they must have a purpose. What do they do? Are they parasites or are they useful members of the community?

It took a long time to discover the functions of the white cells. Haeckel, who is still alive and whose books are well known, discovered nearly sixty years ago that the white cells took up particles of indigo that he had injected into a mollusc. That was an important observation. A few years later, Cohnheim, a celebrated scientist, discovered that the white cells had the extraordinary power of passing right through the walls of capillaries, as ghosts are alleged to pass through closed doors. Then various observers noticed that there were sometimes microbes in the white cells, and began to surmise that the white cells might fight against microbes and devour them. This surmise was finally put to the proof by the great Russian biologist, Metchnikoff, who demonstrated that the surmise was correct and that 'the amœba cells are defensive elements of the body capable of guaranteeing to it immunity and cure.'

The story of Metchnikoff's investigations reads like a romance. He commenced his investigations

by inserting rose prickles into the transparent larvæ of star-fish—rose prickles into the larvæ of star-fish, there is the poetry of the scientific imagination—and discovered that the white cells quickly mobilised and surrounded the prickles.

Then he proceeded to inoculate the Daphnia, a small Crustacean, with the spores of a fungus, and found that the white cells engulfed the spores. Finally, he experimented with the higher mammals, and showed that their white blood-cells devoured and digested the microbes of anthrax and other diseases.

The eating of the germs by the white cells is known as phagocytosis, and the white cells are known as phagocytes. Lord Lister once said, 'If ever there has been a romantic chapter in the history of pathology, it is the story of phagocytosis.'

The white blood-cells, then, are the army and the navy of the body. They are soldiers and marines, they patrol the tissues, and they guard the blood. Let a few anthrax germs or tuberculosis germs be added to the blood, and in a moment the phagocytes crawl to the attack and devour them. Often a single blood-cell will be found to contain several microbes that it has eaten. Sometimes the microbe is too strong and too poisonous and kills the cell, but more often the cell kills the microbe, and microbes in various stages of disintegration are to be found in phagocytes.

But the phagocytes are not proud : they are ready to act not only as soldiers, but also as scavengers. Foreign particles in the blood, such as the indigo particles injected by Haeckel, are promptly seized by them. At times, too, they assist in the construction

of the tissues. They lay down the lime of the bone and then absorb it again that it may be laid more skilfully, and when the tadpole has finished with its tail the phagocytes remove it by devouring it. Sometimes, especially in old age, they become unruly and do those things they ought not to do: they devour the pigment of the hair and turn it grey or white, and they devour the lime of the bones and render them brittle.

We have mentioned how Cohnheim discovered that the white blood-cells pass through the walls of the capillaries, and so get into the tissues of the body. This occurs especially when the tissues are invaded by microbes or irritated by a foreign object. No sooner are the tissues invaded or irritated than white cells rapidly creep through the capillaries and swarm to the seat of invasion or irritation. It is the territorial army rushing to the rescue, prepared to lay down their lives for the sake of their fatherhood. Not only do they mobilise, but they also multiply, so that in a very short time there is an innumerable army of phagocytes ready for the fray. Often they die by the million, and the white creamy matter or pus we see in a suppurating wound or sore consists mainly of dead phagocytes. But, however many die, there are always millions ready to take their place. It seems very possible that, in some cases of microbic invasion, a heavy death-rate results in the evolution of a more resistant race of white cells. Certain it is that in many cases, after millions and millions of deaths, the white cells gain the ascendant over the microbes.

It is surely a remarkable thing that these cells should be so vigilant, and should be so quick to

detect an enemy in the camp. They have a roving commission in the blood, they are outside the control of the nervous system. How then do they know when to fight and what to eat? They are in the midst of countless millions of red blood-cells, but they never eat these, but let a single foreign red cell enter the throng and they pounce upon it at once and devour it. Yet to find a needle in a haystack would be a very trifling task compared with finding the one foreign cell among millions and millions and millions of domestic ones. How is it done?

It has been found that the white cells have tastes and distastes. If fine tubes containing various solutions are introduced into the body of an animal, the white cells are seen to crowd into some and scrupulously to avoid others. And it is usual to explain the movement and behaviour of the white cells by saying that it is a case of chemical attraction or chemico-taxis. That is no explanation at all. No sort of chemical affinity we know will account for the migration of the phagocytes through the capillary wall, and their mobilisation to devour an invading army. Chemical attraction is an attraction between atoms and molecules, not an attraction between bodies of visible magnitude such as an anthrax germ and a phagocyte. Chemical attraction does not explain the envelopment of a microbe on the substance of a white cell. The truth of the matter is that we do not understand phagocytosis at all. All phenomena are in a sense chemico-physical phenomena, but this special phenomenon of phagocytosis is much more nearly akin to the movement of an infant's lips to its

mother's bosom than to any chemical reaction that we can exhibit in a physico-chemical experiment.

Not so many years ago, Sir Almroth Wright made a very interesting discovery. He discovered that there are certain substances, which he named 'opsonins,' in the blood which in some way affect microbes that may be present in the blood, and render them more palatable and attractive to the phagocytes. Thus he found that if microbes and phagocytes were immersed in a certain serum (*i.e.* blood minus fibrin and blood-cells), the phagocytes ate on an average two microbes apiece, while if the same microbes and phagocytes were immersed in another serum they ate four apiece, and in another perhaps six apiece. This would seem to prove that the activity of the phagocytes depended on something in the serum, a something that varied in different serums. This something, as we have said, Sir Almroth Wright called 'opsonin.' He found for various germs there were various opsonins, and he considered opsonin the important factor in phagocytosis. He found, too, that it could be increased in the blood by various injections, *e.g.* of *tuberculin.*

It may be that opsonin plays the important part that Sir Almroth Wright believes it plays; but still the actual eating is certainly performed by the phagocytes, and it is very likely that they themselves have something to do with the preparation of the opsonins.

The white blood-cells live only a few weeks, but as they die new ones are constantly added to the blood by the so-called lymphoid tissues of the blood, especially by the spleen and the lymphatic glands.

The lymphatic glands, indeed, which are swarming with young phagocytes, may be likened to block-houses filled with soldiers, and microbes that penetrate so far are often arrested there and can penetrate no farther.

Besides red cells and white cells, there are usually to be discerned in the blood, little granules known as 'blood-platelets,' but they probably are only precipitates from the blood after it has been drawn, and do not exist in the normal blood in the blood-vessels.

Having now discussed the solid particles in the blood, let us now look at the substances in solution. In solution there are fats, and soaps, and sugar, and common salt, and uric acid, and some other salts and extractives; but the most interesting and important substance in solution is perhaps fibrinogen. For fibrinogen it is that produces, under certain circumstances, the coagulation of blood. Let us look for a moment at the phenomenon of coagulation.

In the blood-vessels the blood is perfectly fluid. Normally it never coagulates as it flows along the arteries, and veins, and capillaries. But when it escapes from the blood-vessels it soon becomes solid unless special precautions are taken.

Plainly, it is very lucky that the blood has normally no tendency to coagulate in the vessels, or we should all be liable to have our circulation blocked at any place at any time.

Plainly, too, it is very lucky that the blood does coagulate outside the vessels, for otherwise we should all be liable to bleed to death every time we cut or scratched ourselves, and, indeed, there are

some people who suffer from a disease, called hæmophilia, whose blood does not coagulate, and who do often bleed to death when an artery is opened.

The coagulum or clot which normally forms in arteries and veins when they are cut, both prevents excessive loss of blood, and serves as a basis for repair: it is the scaffolding, in fact, where the repairers work.

The coagulation of blood is really a very complicated process. When the clot is formed it is found to consist of a mesh-work of fine tough fibres containing blood-cells in its meshes. The mesh-work is made of a chemical substance known as 'fibrin.' But fibrin does not exist as such in the blood, and the process of its formation is as follows.

From the blood-platelets and from the white blood-cells is shed out a material called *thrombogen.* From the blood-cells and from the cut tissues is shed out another material called *thrombokinase,* which in the presence of the lime salts in the blood turns thrombogen into *thrombin* or *fibrin ferment,* which again acts on the fibrinogen in the blood and converts it into fibrin.

Besides these substances we have named, there are also present in the blood various obscure substances that play parts in the fight against microbic disease.

The blood, quite apart from its phagocytes, has bactericidal properties that tend to destroy most microbes that happen to invade it, and globulocidal properties that tend to dissolve red corpuscles of another animal that may be introduced into its stream. These properties are each complex in nature: each consists of a substance known as the *immune body,*

and another substance known as the *complement*. The immune body varies according to the nature of the microbe or red cell to be destroyed, and acts as an intermediary, so that the complement can do its destructive work. It has been aptly compared to a key, and the complement to the hand turning the key.

It is an amazing thing that the blood should have various keys to fit various microbes and red cells; but more wonderful still, it has the power of multiplying its keys, so that it can get at the heart of more and more microbes, and thus become more and more resistant to the disease, and so that a little of it transferred to the blood of a less resistant animal will increase its powers of resistance.

The blood has also the power of forming antitoxins to neutralise various toxins; and by a gradual increase in the dose of toxins the blood may be rendered very rich in antitoxins, and injected into an individual less resistant to the toxin may increase his resistance; but we shall return to this subject when we come to treat of disease.

Meantime we may briefly summarise as follows the facts of blood resistance to microbic disease. There are three ways in which the blood can resist the microbes. The phagocytes, with the assistance of opsonin, may devour them. The serum, by means of the immune bodies and the complement it contains, may destroy them. The serum, by means of antitoxins, may neutralise the microbic toxins.

The extraordinary precision of the reactions of the blood is well seen in the precipitin test. If human blood be added to the blood of a rabbit, the blood of the rabbit develops antitoxins to protect it from

human blood, which acts as a toxin to it. Not only so, it also develops some substance in it known as 'precipitin,' so that when a little of the rabbit's anti-toxin blood is added to human blood, it produces a precipitate in the blood. In no other blood will it produce a precipitate, only in human blood; and by using such blood as a test we can always decide whether any given specimen of blood is human. This test will detect the nature of the blood, even if it be greatly diluted, or even if it has been dried for weeks.

The blood, then, must be recognised as a very marvellous fluid swarming with most remarkable cells, red and white, and capable of most complex chemical reactions against disease.

CHAPTER XI

THE RESPIRATION

The world began, so most physicists tell us, as a sphere of seething, surging, blazing gases—gases of iron, gases of lead, gases of chlorine, gases of sodium, gases of water, gases of mercury, gases of all the elements, in fact. By degrees these cooled, united into compounds and formed solids, until now we have a solid world some 25,000 miles in circumference. Luckily, or rather providentially, the gases of air were left still as gases, and water was left in a condition alternating between a vapour and a fluid. Had that not been so, life could never have been, for both air and water are essential to life. In this case Nature certainly did not make experiments; she arranged matters in such a way that she went straight to her goal, and left uncondensed on the surface of the world both air and water—just the very two things, and the only two things, that life could not do without.

It seems probable that both air and water were mainly volcanic products, but, whether volcanic products or residua, they certainly came just in the right place at the right time. Water without air had been futile, for if Nature had proceeded to elaborate the wonderful compound of life known as 'protoplasm,' it could not have lived without oxygen; and it could not have continued to live without carbon. But the air was ready there when Nature

made her first protoplasm, and life began by the interplay between the oxygen of the air and the molecules of the protoplasm, and was perpetuated, with the help of the sun, by the continual addition of carbon and nitrogen to replace atoms broken away during or after oxidation. The interplay between the protoplasm of the living tissues and the oxygen is always associated with a production of heat, and is of the same nature as the interplay between the molecules of a burning match and the oxygen of the air. In other words, it is a process of combustion. If we expose the carbonaceous matter of rotting hay to the air the carbon burns. If we expose an amœba to the air the amœba burns. If we expose the tissues of the body to the oxygen collected from the air by the red blood-cells the tissues burn.

In the case of living organisms we call the combustion 'respiration.'

In the lower unicellular organisms respiration is a very simple matter. All that is necessary is simply contact between the surface of the organism and the oxygen of the air. The cell simply lies in the air, or in water containing air, and slowly burns. The oxygen enters into chemical combination with its tissues, and then flies off again wedded to the carbon of the tissue as carbon-dioxide. In larger organisms, special means are requisite to bring the oxygen into intimate contact with the tissues. The higher animals have gills and lungs where oxygen is gathered by the red blood-cells, and a heart with a system of vessels to carry the red cells with the oxygen to all parts of the body.

It is curious to notice how the early scientists

blundered in their ideas of the functions of the lungs. Aristotle, for instance, taught that the air was carried by the windpipe to the heart in order to mitigate the heart's heat. 'The hotter the animal,' he writes, 'the more vigorously must it breathe in order the more effectually to subdue the heat.' And on this theory he supposed that fishes died on land because their hearts were excessively cooled, and that animals died under water because their hearts were not cooled enough.

Galen, on the other hand, considered that the air went to the heart to be concocted with the blood there into vital spirit, and this doctrine persisted till the time of Harvey.

Not till towards the end of the seventeenth century was the true nature of respiration surmised, and not till the eighteenth century were the principles of the process really understood.

Let us now briefly describe the structure and functions of the respiratory organs in man according to modern science.

In man the respiratory apparatus consists of the mouth, nose, larynx, trachea, bronchial tubes, lungs, and whole vascular system.

The nostrils, not the mouth, are the portals of the air: they contain little thin curled scrolls of bone, the so-called turbinal bones, covered with mucous membrane which are for the purpose of filtering, moistening, and warming the air. The mucous membrane of the bones presents little hair-like processes towards the interior of their nostrils, and these little hair-like processes are in constant movement and gradually flick foreign particles and germs out of the nostril. The mucous membrane

is also moistened with sticky mucus, which both entraps and kills germs much as sticky fly-papers entrap and kill flies. It has been found that if air containing thousands of germs is inspired through the nose only two or three germs succeed in passing through, and it has been found, too, that most germs trapped on the mucous membrane of the nose are soon killed. Not only does the mucous membrane, spread over the curled bones, offer an extensive surface to catch germs, but the devious crooked course of the nostrils also offers obstacles to the passage of germs.

The functions of the nostrils in heating and moistening the air are equally efficient. Air, 14° Fahrenheit below freezing-point is heated to 77° Fahrenheit during its passage through the nose; air at 65° Fahrenheit is heated to 88° Fahrenheit; while dry air is always moistened with water to one-third of its capacity before it reaches the throat. People, therefore, who breathe through their noses, as they should, need not fear that cold air will be bad for their chests, for cold air will never reach their chests.

The air is drawn through the nostrils and then through the larynx, trachea, and bronchi into the lungs by the muscular mechanism of the respiration, and this we must now explain.

The lungs, consisting essentially of branched air tubes and air sacs, along with net-works of blood-vessels, are placed in air-tight compartments within the chest wall. When, therefore, the chest expands, the lungs expand too, and air rushes in through the nose trachea and bronchi just as air rushes into a bellows when we expand the bellows.

We need not enter here into the question of the particular muscles that expand the chest, and into the mechanical principles of its expansion. Suffice it here to say that the muscles most concerned are the rib muscles and the big plate-like muscle called the diaphragm which forms a transverse partition between the chest and abdominal cavities. The chest cavity contracts again, partly because the ribs and chest-bone fall of their own weight, partly owing to the elastic pull of the lungs. The muscles that expand the chest contract about sixteen times a minute; and sixteen times a minute the chest expands and draws in air, and contracts and expels the air again. The amount of air inspired and expired depends on the size of the chest and on the extent of its expansion; but, whether the quantity be big or small, during life the ebb and flow never cease. The object of the movement, as we shall soon explain, is to permit of an exchange of gases in the air vesicles in the lungs.

The full amount of air a man can inspire after emptying his lungs as forcibly and fully as possible, is said to be his *vital capacity*. Before going farther, however, let us point out that, contrary to popular opinion, a big chest is not necessarily a good chest, and that exercises to expand the chest often impair its efficiency as an organ of respiration. In order to produce a good tidal flow of air, it is more necessary that the chest be mobile than that it be big. The value of a chest as a breathing organ depends on its expansibility; and a small chest that expands, on inspiration, three or four inches is worth more than a big chest that can expand only an inch and a half.

Dr Harry Campbell, who has made a special study of the physiology of respiration, found the greatest breathing capacity he came across in a tall man with a chest measuring only 35 inches, and he found that the huge chest of the champion weight-lifter of the world had very small breathing capacity. Many of the big chests developed under the old system of physical development in the army were quite fictitious; they were simply chests permanently pouted out, and so fixed in the pouting position that their breathing power was impaired. There are many exercises that in increasing the chest's measurement diminish its mobility. All muscular exercises that require for their performance a fixation of the chest are to be avoided.

Further, it must not be supposed that the development of such muscles as the pectoral and latissimus dorsi round the chest wall improve its respiratory capacity; they give a man a beautiful torso, but they do not necessarily increase his breathing power, and may reduce it.

Mobility of chest is the quality that is to be aimed at, and this can be better attained by breathing exercises than by muscular development, and best of all by the breathing efforts that involuntarily follow active exercise.

We sometimes hear of chests of fifteen or twenty inches expansion. No chest can expand fifteen or twenty inches, since the ribs are not made of elastic. The alleged expansion of the chest is really only an expansion of big muscles contracting around it.

The ordinary respiratory movements of the chest, be it always remembered, are instigated and regulated

by the respiratory nervous centre at the top of the spinal cord, and though we can deepen, or quicken, or slow them at will, no effort of will can train them to be consistently faster, slower, or deeper, or more shallow, than the nervous centre decides they ought to be. The decision lies in the hands of the breathing centre, and the breathing centre gets its cue mainly from the gaseous chemistry of the blood, but also from nerve messages from the skin and other parts. We may religiously carry out breathing exercises for so many minutes a day, and by so doing we may assist the heart and massage the liver, and do some other things; but the moment the will ceases to act, the breathing returns to its normal rate and depth, as settled by the requirements of the system—by the amount of carbon-dioxide in the blood, by the temperature of the skin, by the rate of the circulation, by the quality of the red blood-cells, by the posture of the body, and other circumstances. There are none of the functions of the body more beautifully and wisely adapted by automatic reflex processes to the needs of the organism. A little snuff up the nostrils, or a little sunlight in the eyes, makes one sneeze; a crumb in the throat, or a tubercle bacillus in the lungs, makes one cough; a little sorrow makes one sigh; a little excess of carbon-dioxide makes one breathe more deeply. Never for a moment does the central nervous system relax its vigilance or drop its reins: night or day, asleep or awake, it still adapts the breathing to the necessities of the case. All that we can do is to keep the chest limber, so that it can do extra work when required.

The air, then, inspired in the manner aforesaid, is sucked into the lungs. The trachea or windpipe divides into two branches called the *right* and *left bronchi*, which go to the right and left lung respectively, and divide and subdivide, growing smaller and smaller with each division, till they become almost microscopically fine. Ultimately each fine branch ends in a small elongated sac or *infundibulum*, like the blown-out finger of a glove, dimpled over its interior with closely-set little cup-like depressions that bulge on the exterior of the infundibula, so that, seen from the outside, they resemble bunches of microscopic grapes. All the branches, large and small, with infundibula and air-cells are set closely together, and are bound together by fine elastic connective tissue and interwoven with nerves and fine arteries and veins, so as to form soft fleshy masses which are encased and held together by a delicate membrane known as the pleura. Each lung, further, is partially subdivided by straight deep fissures into separate portions called *lobes*. The right is subdivided into three lobes, and the left into two. Thus constituted the lungs are evidently porous and elastic masses, and, therefore, they tend to shrink together and collapse when taken out of the body.

All the air tubes, except the final finest divisions, are lined with cells whose surfaces, abutting on the cavity of the tubes, have hair-like prolongations which are in constant motion, and move in such a way as to work mucus and any foreign particles gradually upwards towards the throat. The surface lining of the tubes is very smooth and glistening, and is lubricated by a secretion (the *mucus*) like

raw white of egg, which is secreted by means of mucous glands.

The air-cells are very delicate structures, and consist of little more than a single layer of cells and a little connective tissue. The arteries that penetrate the lung and branch among its air tubes terminate in dense mesh-works of exceedingly fine capillaries that cover the outsides of the air-cells. Thus, in the air-cells the oxygen of the air is separated from the red blood-cells in the capillaries only by the very thin wall of the capillary and the very thin wall of the air-cell, and this is near enough to allow oxygen in the air to pass through the double walls into the blood and to join the hæmoglobin of the red blood-cells, and also to allow carbon-dioxide in the blood to pass from the blood of the capillaries into the air in the air-cells. The surface, so contrived, at which gaseous interchange can take place is surprisingly large. We have pointed out, in the previous chapter, that the capillaries in the lung if stretched out into a single line would reach across the Atlantic, and we pointed out, too, that red blood-cells in the aggregate present a surface of over 3300 square yards, or in single file would extend over 200,000 miles. In the capillaries of the lung the red cells are in single file, so that the total surface they present, though not very wide, is as long as from London to New York. It has been calculated, again, that there are over 700,000,000 air-cells with a total surface of over 120 square yards (enough to cover the floor of a room 10 by 12 yards). So we may say that 3300 square yards of red blood-cell surface, bit by bit, by means of a river

thousands of miles long, is brought into contact with air over a surface measuring 120 square yards. Roughly speaking, by the time the capillaries of the lungs have been filled thirty times with blood, 3300 square yards of blood-cell surface have had an opportunity to take up oxygen, and a river of blood some 200,000 miles in length has had an opportunity to give up carbon-dioxide to the air in the air-cells. The amount of air, again, that is passed in and out of the lungs of a man at rest has been estimated as 680,000 cubic inches in 24 hours. These figures are bewildering, but they show what extraordinary ingenuity Nature has shown in order to ensure that the body of man has a chance to get oxygen and to give up carbon-dioxide.

The intake of oxygen by the blood is partly a physical, partly a chemical, and partly a vital matter; but the net result is that the tissues obtain the oxygen they require, and that the supply varies with the demand.

Normally, when awake, a man of average size takes into his blood about three-quarters of a pint of oxygen per minute, but, when asleep, he takes in less than half a pint, and when doing violent exercise his blood may absorb five or six pints a minute.

Among mammals the proportional intake of oxygen varies inversely, *ceteris paribus*, with the size of the animal. Thus the mouse absorbs, in proportion to its weight, ten times as much oxygen as a dog, and a dog twice as much as a man.

The same relationship obtains also, to some extent, among birds and the lower animals; thus a sparrow, in proportion to its weight, consumes eight times

as much oxygen as a hen, and about thirty times as much as the average man. The reason of this is mainly that the smaller the animal the greater its surface in proportion to its weight, and the greater, therefore, the radiation of heat in proportion to its weight. To keep up its temperature, therefore, the smaller animal must burn faster, and to burn faster it requires more oxygen.

The blood, which has acquired oxygen by the complicated processes we have just sketched, is pumped by the heart into the capillaries of the various tissues of the body, and the oxygen passes through the lymph, bathing the tissues, into the tissues themselves. The various tissues absorb oxygen in degrees varying with their special activity. Glandular tissues seem to require most oxygen, then muscular tissues; while nervous tissues and connective tissues seem to require comparatively little.

The tissues not only take oxygen from the blood, but also give to the blood the carbonic acid formed as one of the products of their activity, and this, as we have already mentioned, is given up from the capillaries of the lungs to the air in the air-cells.

The lungs and air passages also give up heat and water-vapour to the air. However cold and dry the air may be when it is inspired, it is always heated to body temperature and saturated with moisture when it is expired. A considerable quantity of heat is given off in this way, and about a pint of water every twenty-four hours. It is evident, however, that the amount given off of both must vary with the temperature and humidity of the air.

The gaseous interchanges in the tissues are known as *internal* or *tissue* respiration; and the respiration in the lung is only for the purpose of facilitating this tissue respiration, which is the real respiration on which life, and heat, and activity depend.

A man may breathe as deeply as he likes, but it will avail him nothing unless he have plenty red cells to collect oxygen, a good heart to pump them to the tissues, and healthy tissues ready to receive the oxygen. We are accustomed to regard pallor as a sign of debility, and ruddiness as a sign of vigour and energy, and, with certain reservations, such an interpretation is quite correct, since ruddiness means, usually, plenty of red blood-cells, plenty of torches to keep the fire of life going, and pallor means that there is a deficiency of red blood-cells with all that deficiency involves.

The exact nature of the oxidation that occurs in the tissues, and that gives rise to heat, and secretory, and muscular, and nervous energy, we do not quite understand. We talk of combustion, but the combustion that takes place in the body is of a very mysterious kind. The normal temperature of the human body is only 98·6 Fahrenheit or thereabouts, and protein, and butter, and carbohydrates do not oxidate and burn at that temperature in the presence of oxygen. It is probable that the oxygen enters into combustion with the living tissues, and forms unstable compounds that break down and are then oxidised with the evolution of heat and energy. But even so, it is difficult to understand how the chemical energy or heat is converted into the mechanical energy of muscular movement, and into

the energy of thought. We must just take it as a fact that oxidation does occur, and that its occurrence is associated with energy of different kinds and with heat.

Respiration, that is to say the interchange of gases that takes place in the lungs and in the tissues, is influenced to some extent by air-pressure. Thus, at ordinary atmospheric pressure the red blood-cells are about 80 per cent. saturated with oxygen, while at a quarter of ordinary atmospheric pressure they are only 70 per cent. saturated. Accordingly, at great heights, where the atmospheric pressure is diminished, there is less oxygen carried by the red blood-cells to the tissues. To compensate for this, the heart beats more quickly so that more blood is driven through the tissues in a given time—a case of small profits quick returns—and more red cells are formed, so that they may make up in number what they lose in carrying capacity. Some years ago Professor Kronecker, of Berne, arranged that eleven people should be carried from Zermatt (1600 metres) to the plateau of the Breithorn (3750 metres). In every case the heart-beat was found to be accelerated. Monsieur Lortel, of Lyons, found that his pulse-rate, which was 64 at Lyons, became 94–108 on Mont Blanc. The average number of red blood-cells per cubic centimetre at sea-level is 5,000,000, over 6,000,000 at Davos (1560 metres above sea-level), over 7,000,000 at Arosa (1800 metres), and 8,000,000 on the Cordilleras, at a height of 4392 metres.

Owing to these compensatory arrangements, men with sound hearts are able to live at great heights, without inconvenience or detriment to health—at heights, indeed, where many plants and animals

die. Boussingault remarks: 'After looking at the bustle of traffic in towns like Bogota, Micuipampa, Potosi and such like, at elevations of 8000 to 12,000 feet; after witnessing the strength and the marvellous skill of the toreadors in the bull-fights at Quito, 9000 feet above sea-level; after seeing young and delicate girls dancing a whole night at places as high as Mont Blanc, on which the celebrated Saussure had hardly strength enough to use his instruments of observation, and his hardy guides fell down in a swoon as they proceeded to dig a hole in the snow; when we remember, finally, that a famous battle, that of Pinchincha, was won almost at the altitude of Monte Rosa; I think you will agree with me that man can become adapted to breathing the rarefied air of the very highest mountains.'

There is, of course, a limit to man's compensatory powers in this way. At a height of 29,000 or 30,000 feet consciousness is lost and death follows, even in the case of those habituated to high altitudes, and, accordingly, the highest peaks of the Himalayas can never be scaled without the aid of oxygen cylinders.

If one climb too quickly to a great height the result is a condition called mountain-sickness. There is breathlessness, headache, muscular weakness, and there may be vomiting and delirium. This condition is due to lack of oxygen, and it may be produced even in a resting man if the air-pressure be sufficiently reduced.

Since lack of oxygen is so harmful, it might be thought that inhalations of oxygen should be correspondingly beneficial. But this is not so. For

all ordinary purposes, there is far more oxygen in the blood of a healthy man than his tissues can use. Only under normal conditions, when the supply of oxygen is deficient or when the demand for oxygen is excessive, can oxygen inhalations be of use, and even then their usefulness is limited. It is useful, for instance, if a man be suffering from lack of oxygen owing to some impediment to full respiration, such as occurs in pneumonia, or bronchitis, or consumption, but it is useful only if the heart and red cells be able to transport it to the tissues. If there be heart disease with a failing heart, or anæmia with deficiency of red blood-cells, the oxygen can do little good except in so far as it may stimulate the heart.

In certain cases where a man's nervous and muscular system are strong enough to use up oxygen faster than the blood can convey it, an extra supply of oxygen, provided by inhalation, may be serviceable both in removing fatigue products such as lactic acid, and in providing more oxygen for driving purposes. Two or three years ago, the well-known physiologist Professor Leonard Hill gave oxygen to some runners before short races, and found that the runners made better times and suffered less from fatigue. Mr Just, a well-known runner, who, after a few minutes of oxygen inhalation, beat his previous best time for the half-mile, declared: 'While running I felt extremely light on my feet, running for the most part with very little exertion. A remarkable fact was that after running, my legs were not at all stiff as they usually are after a hard run. After the quarter they were so supple and springy as if

I had not run at all. Even though I had to run much within a very short space of time I did not feel in the least tired.

'I travelled so easily that the pace seemed much slower than it really was; and even sprinting, which usually tires me very much, seemed quite easy, although I had just run a half and a quarter mile. . . . In conclusion I might say that I felt no after effects at all.'

Another runner, Mr H. E. Holder, who also succeeded in beating his previous best times, 'noticed the absence of distressful dyspnoca, of grogginess, and of stiffness in the legs, and was able to run with unusual ease.'

Professor Hill likewise experimented with Wolffe, the channel swimmer, on one of his attempts to swim across the Channel. Wolffe refused the help of oxygen till he was so far done that he talked about coming out, and was thoroughly disheartened. 'On breathing oxygen, the done-up man, who was wasting his breath in talking, quieted down, his breathing became slower and less distressed, he stopped talking, and plugged away again in workman-like fashion.' Dr Martin Flack, who gave the swimmer the gas, says: 'The bag was emptied with such amazing rapidity and completeness that a leak seemed probable, and a big leak too. A leak indeed there was, but careful inspection showed that it was only into the alveoli (air-cells) of an oxygen-starved man.'

In such exceptional instances, then, oxygen may be useful; but taken as an everyday stimulant, under ordinary circumstances, it would do no good at all.

It may be interesting to note that after forced breathing and oxygen inhalations a Dr Vernon was able to hold his breath for the extraordinary time of 8 minutes 13 seconds.

Now let us look for a moment at the question of the heat of the body, which, as we have already seen, is intimately related to respiration.

Man lives for seventy years or so in an environment whose temperature is constantly changing, and varies from 100° Fahrenheit or more below freezing to 100° Fahrenheit or more above freezing, and yet for all these years, howsoever much the temperature of its environment may change, his body maintains a steady temperature of 98° Fahrenheit to 99° Fahrenheit—if we except a few temporary rises of a few degrees due to ill-health or violent exercise.

Only very rarely is man's environment warmer than his body: as a rule it is colder, and the oxidative processes of the body have to be in continual action to compensate for loss of heat through radiation, convection, conduction, and evaporation. Day by day, hour by hour, the body is subject to changes of temperature, and yet it maintains its own temperature unchanged.

The temperature is produced by the oxidative processes in the body, and of the 3000 calories of energy produced in man under ordinary conditions, by far the greatest part takes the form of heat to warm the body or its surroundings. All the millions of little red torches that run along the capillaries are mainly occupied in warming the body.

Most of the oxidation and combustion that

warms the body takes place in the liver and the muscles. The liver contains about a quarter of the whole blood in the body, and oxidative chemical processes are constantly performed in it, so that the blood leaving the liver is the warmest blood in the body. The muscles again are in constant action: even at rest they are in a state of tonic contraction.

That is where most of the heat is formed. But how does it come to be formed so judiciously with a due regard to the special requirements of the moment? How does it happen that the body does not reach boiling-point, or sink occasionally to the temperature of a winter day?

The constancy of the temperature of the body is produced in two ways: in the first place, by judicious modifications of the production of heat; and, in the second place, by ingenious arrangements for the loss of heat. As the surrounding medium grows colder, the muscles and glands, instigated no doubt by nerve centres automatically set in action, form more heat—the liver works more actively, the tone of the muscles is increased. Not only so, but physiological arrangements are also made to retain the heat—the blood-vessels in the skin contract, the breathing becomes more shallow, etc. Similarly, when the surrounding medium grows warmer, heat production is diminished, the muscular tone, as we know, is relaxed, the liver works less actively, and heat loss is increased by a dilatation of the blood-vessels in the skin by the pouring out and evaporation of sweat, and in other ways. A balance is struck between income and expenditure, so that the tem-

perature is maintained steady at 98° Fahrenheit to 99° Fahrenheit.

The regulation of temperature becomes more difficult, and is more prone to fail, when the temperature of the surrounding medium is greater than the temperature of the body. In some cases the temperature of the body runs up, and heat apoplexy is the result. Even in such cases, however, the body shows a wonderful power of keeping cool. Workers in foundries have sometimes to endure a heat of 250° Fahrenheit, and Chabert, the so-called Fire King, was able to enter an oven at a temperature of 400° Fahrenheit.

When man's temperature reaches a height of 108 or 109° Fahrenheit, death inevitably ensues, and a fall below 95° Fahrenheit usually betokens impending death. Seeing how ingenious and how successful are Nature's methods of maintaining the body at a steady temperature, we are not surprised to find that most disturbances of temperature are due to disease, chiefly to microbic diseases, which are hence often called fevers—scarlet fever, typhoid fever, and so on. In these cases Nature's wonderful regulation of heat production and heat loss is disarranged.

There are few things more wonderful about the burning bush of the body than the steadiness of its temperature as it burns and burns from day to day and from year to year.

CHAPTER XII

THE DIGESTION

Man grows from a microscopic ovum into a complicated structure known as an infant, by a process of adding molecule to molecule, and molecule to molecule, just as they are given to his blood by the blood of his mother. Up till the day of his birth the infant gets his material ready-made. But after birth, if he is to exercise energy and to continue to grow, he must collect material for himself, and prepare it for use in the long, dark factory known as the alimentary canal. At first he is given the best raw building material known: he is given his mother's milk. In that wonderful fluid is matter for fuel and energy, together with every brick that can be possibly used for building human tissues. And by and by he is weaned and gets teeth, and new digestive juices, and he starts to use the various foods that men have discovered. Let us look for a moment at the mechanism and chemistry of the digestive system that builds and repairs the body, and furnishes it with fuel to keep it warm, and with force for its various activities.

The apparatus is essentially an irregular tube several yards in length. It commences under the eyes and nose at the orifice known as the *mouth*, which is furnished with little grasping, grinding, and tearing tools of hard lime known as the *teeth*. It continues as a narrow tube known as the *gullet* or

œsophagus, for a foot or so to the muscular pouch known as the *stomach*. From the stomach it continues as a narrow much-looped tube about 22 feet in length, which abruptly passes into a larger, shorter tube known as the *large intestine*, and the large intestine terminates in the *rectum*, where the residue of food is excreted. That in a very general way is the conformation of the factory where foods are made into force and living tissues; and, before we consider it more in detail, it will be well to take a glance at the nature of the raw material or food that is manufactured.

As we saw in the first chapters, the tissues of the body are composed of carbon, hydrogen, oxygen, nitrogen, sulphur and phosphorus, with water and a few salts. All its constituents are common enough: the air is full of carbon, hydrogen, oxygen, and nitrogen; and sulphur and phosphorus are as common as Bryant and May's matches. But man can use for purposes of food only such combinations of these elements in which (as we described in Chapter II.) the energy of the sun is hid—in other words, man can use only compounds that living things, plants, and animals have made with the assistance of the sun. Only thus can he acquire, with the molecules he collects, the energy that will make him a living man. All this we have explained in Chapter II., and so need not further pursue the subject here. Man cannot, therefore, eat black carbon, or make much use of hydrogen gas; but still he has a pretty big menu to choose from—beef, and mutton, and ducks, and hens, and grouse, and ptarmigan, and salmon, and lobster, and wheat, and oats, and milk, and potatoes, and nuts, and apples,

and grapes, and turtle, and caviare, and hundreds or thousands of other articles.

Regarded chemically, all these articles of food may be divided into three classes: (*a*) Proteins, such as the white of egg, or the lean of meat, which contain carbon, hydrogen, oxygen, and nitrogen; (*b*) carbohydrates, such as starch, cane sugar, or grape sugar, which contain only carbon, hydrogen, and oxygen, and the latter two elements in the proportions in which they occur in water; (*c*) fats which contain only carbon, hydrogen, and oxygen, and are compounds of fatty acids and glycerine. The first class, since they contain nitrogen, are often called nitrogenous substances, and the latter two classes, since they contain no nitrogen, are often called non-nitrogenous substances.

These are the great classes of food substances; but most foods contain two or three of these. Milk contains protein, carbohydrate, and fat; bread contains protein, carbohydrate, and fat; potatoes contain protein and carbohydrate, and so on. Since the tissues contain nitrogen, it is quite plain that no carbohydrate food or fat food can be a complete food. But later on we shall discuss the fuel and force value of various foods. Meantime we have to see how the main food substances we have mentioned are digested in the alimentary canal.

The food, then, consisting of proteins, and carbohydrates, and starches, begins its alimentary career in the mouth. The mouth, by means of the teeth, which are admirably adapted for the purpose, tears, cuts, and crushes the food, and, with the aid of the tongue, mixes the food with a slimy watery secretion known as *saliva*. The saliva is

secreted by six glands, three on each side, and not only moistens the food, but by means of a chemical substance called *ptyalin* it splits any starch in the food into *dextrin* and *maltose.* The secretion of the saliva is under the control of the nervous system, and is excited by the nerves of taste, sight, and smell, and it flows more copiously if the food be dry. A man secretes on the average no less than two pints a day of saliva, and herbivora secrete it by the gallon.

The food, insalivated and moister, is then swallowed and passes down the gullet to the stomach. Swallowing seems a very easy act; but it is really difficult and complicated, for the food has to be steered past the larynx and the posterior orifice of the nose, into the gullet. Once, however, the food is in the throat the action of swallowing is reflex, and whether it be a pill, or a peach, or a feeding-tube, down it goes.

The food having passed down the gullet, reaches the stomach: this is essentially a muscular bag or pouch lined with mucous membrane. The muscles are arranged in three layers, one layer with fibres arranged circularly, another with fibres arranged longitudinally, and a third with fibres arranged obliquely. The contraction and relaxation of these fibres naturally moves and churns the food in the stomach. The mucous membrane of the stomach is pitted with tiny depressions, and in the depressions are to be seen the minute openings of the gastric glands that secrete the gastric juice. The gastric juice contains a chemical substance, *pepsin*, and hydrochloric acid, and these together act upon protein in the food. It also contains a substance,

lipase, that splits fat into glycerine and fatty acid, and a substance, *rennin*, that curdles milk. Gastric juice, indeed, has five actions. Its acidity kills most micro-organisms that may be in the food, and also changes cane sugar into the sugars known as *dextrose* and *lævulose*. The lipase splits fats; the rennin curdles milk; and the pepsin and hydrochloric acid acts on the proteins. The most important action of the gastric juice is the action of the pepsin-hydrochloric acid upon the protein: that is the main part it plays in the digestive programme.

The action of the saliva on the starch of the food continues for some time after the food has reached the stomach; but as soon as the food is acidified the action ceases. The secretion of gastric juice, like the secretion of saliva, is largely under the control of the nervous system. Before the food reaches the stomach, the sight, taste, and smell of the food may cause an outflow of gastric juice, and, therefore, it is good that food should be tasty, and should be smelt and tasted. This juice secreted *before* the food enters the stomach is sometimes called *appetite* juice. *After* the food reaches the stomach the amount of secretion it excites depends on the nature of the food. White of egg and bread excite almost no secretion, while milk, and meat extracts, and dextrin cause a good flow. The flow is a matter of chemical stimulation: the first products of digestion stimulate the glands of the stomach.

It is interesting to note that the dietetic instincts of man make him begin his dinner very often with bread and soup or meat extract. The bread going

to the stomach as dextrin, and the meat extract, both excite a flow of gastric juice, and, therefore, ensure digestion of the later courses. From the stomach, after a variable interval, the food is passed along through the loop of bowel known as the *pylorus* into the *small intestine*. At this stage the food is called *chyme*, and as the chyme passes through the pylorus it is acted upon by the pancreatic juice of the pancreas or sweet-bread, which flows into the intestine at this point. For a long time it was not understood how it happened that the pancreatic juice was stimulated to flow just as the chyme passed through the pylorus. Quite recently it has been found out that the acid chyme, as it passes through the pylorus, causes the secretion in the cells of the pylorus of a substance called *secretin*, which is carried in the blood stream to the pancreas and excites its secretion. The pancreatic juice is alkaline and, as it is poured out, it soon neutralises the acid chyme. No more secretion is then produced, and the flow of pancreatic juice fails till secretion is again produced by a gush of acid chyme. It is thus an automatic chemical action.

The pancreatic juice is the most powerful and versatile of all the digestive juices. Like ptyalin, it converts starch into maltose: like pepsin, it splits up proteins; and it also splits fat, and curdles milk. Its action on starch is very powerful and rapid, and it quickly turns any starch in the food into maltose. On protein its action is equally powerful. The gastric juice, as we have seen, splits the protein of the food into peptones; but the pancreatic juice carries the splitting much

farther: it breaks the protein into peptones first, then into smaller bits called *polypeptides,* and ultimately into smaller bits still known as *amino-acids.* The fats are split into fatty acids and glycerine, and the fatty acids unite with alkaline bases which are present and form soaps, and the soaps again form fine emulsions with the unchanged fats. Milk is clotted much in the same way as by gastric juice; but, as a rule, all milk is clotted before it leaves the stomach.

Pancreatic juice is thus a very strong digestive agent, and is capable by itself of digesting all kinds of food; but the assistance it receives from the salivary and gastric juices is not to be despised, and it must be remembered that it is digestion in the mouth that stimulates digestion in the stomach, and the acid juices of the stomach that stimulate the secretion of the pancreas.

In the duodenum the food is also subjected to the action of the bile, but bile has little digestive action: it merely assists the pancreatic juice in the digestion of fats.

We have said that pancreatic juice has the power of splitting proteins into amino-acids; but this is not quite true: it has the power only after it has been mixed with the digestive juice of the small intestine, and acted upon by a substance called *entero-kinase.* The entero-kinase converts a substance, *trypsinogen*, in the pancreatic juice into another substance, *trypsin*, and it is trypsin that splits the protein. The substance in the pancreatic juice which digests starch is called *amylopsin*, and the substance which digests fat is called *lipase.*

Besides entero-kinase, the juice of the small intestine contains another substance, *erepsin*, which splits peptones and other products of protein digestion, and digestive substances that act on sugar. In young animals there is also a substance that acts on milk. The substance that acts on sugar is most important, for it converts the sugar *maltose*, which cannot be absorbed, into the sugar *glucose*, which is readily absorbable. The large intestine has little or no digestive action, but it secretes mucus which acts as a lubricant.

Both the small and the large intestine are swarming with micro-organisms, some of which assist digestive processes.

It will be seen that the process of digestion is a very complicated one, and that the different stages of it are closely correlated. The net result is that the carbohydrates are converted into sugar, the proteins into amino-acids, and the fats into fatty acids and glycerine.

Now then what is the meaning of these changes? The food is changed that it may be absorbed. It is broken down that its fragments may be borne in the blood to the tissues, and there used for building and fuel purposes. It is quite plain that a mutton chop, or a banana, or a lump of butter, cannot, as such, enter the blood; but even if they be ground exceedingly small, they cannot enter the blood stream or the lymphatics. The main purpose of the processes in the alimentary canal is to render the food absorbable.

Having been changed into sugar, and amino-acids, and fatty acids, and glycerine, the food is then

absorbed. Let us look for a moment at the manner of this absorption.

The products of digestion are absorbed either by the blood-vessels of the intestines or by the lymphatics, and, in a general way, the proteins and carbohydrates are absorbed by the blood-vessels, and fats by the lymphatics.

Practically no absorption takes place in the mouth and gullet, and very little takes place in the stomach. The popular idea that the stomach does the greater part both of digestion and absorption is quite wrong. Not even water is absorbed by the stomach. The real business of absorption begins in the duodenum, and it is most vigorously carried out in the small intestine. The small intestine has little projections, *villi*, like the pile of velvet, and various folds to increase its surface. Without villi-folds the surface of the bowel would have an area of less than two square yards, whereas with villi and folds it presents a surface of more than fifty square yards. Over these fifty square yards glucose and amino-acids are vigorously absorbed.

It must be understood, of course, that the food during digestion is propelled along the intestines by circular and longitudinal muscular fibres in its wall. The actual process of absorption is not fully understood: it does not follow the general laws of osmosis and absorption: it depends in some obscure way on the vital activities of the living cells.

All the carbohydrates in food enter the blood as the sugar glucose, and the glucose is carried by the blood to the liver, where it is converted into glycogen and stored up for after use.

The proteins in food are absorbed in the very

fragmentary condition of amino-acids. The amino-acids are very closely connected with fatty acids such as ascetic acid, and an animal can obtain his nitrogen from them if he be fed on them. All the proteins are built up of several of these amino-acids. Thus egg albumin contains leucine, glutamic acid, tyrosine, cystine; and caseinogen of cow's milk contains leucine, glutamic acid, tyrosine, arginine, tryptophane, cystine. For years chemists have been breaking up various proteins into various amino-acids, and Emil Fischer, of Berlin, and others, have also been trying to put them together again, and have managed to form polypeptides.

The fats in food are absorbed by lymphatics known as lacteals, which run in the centre of the villi of the small intestine. They are absorbed as fatty acids and glycerine, and as the acid and glycerine pass through the cells that cover the villi, they are compounded by the cells into fat again. The fat droplets eventually flow into the great lymphatic vessel, the *thoracic duct*, and are discharged by it into the blood, and after a fatty meal the blood may look quite milky.

What happens to the food after absorption? The glucose is converted by the liver into glycogen, which is a carbohydrate, and then reconverted at need into glucose again, but we do not understand by what chemical processes these changes are effected. The glucose is then taken up by the muscles, is oxidised in their tissues and used as a source of energy. The amino-acids are partly used for building purposes, and are partly broken up in the liver with the formation of urea, but again we do not understand the chemistry of the processes.

The fat which enters the blood, in the way we have described, is stored in cells forming adipose tissue and serves as a source of heat and muscular energy, and it is also probably incorporated in living cells in the form of lecithin.

Proteins, carbohydrates, and fats are the food substances of man, and they are digested, absorbed, and used, as we have just related. But how about the quantities of each requisite to maintain the health and energy of a man? Are all three necessary, and if so, in what quantities and proportions should they be taken?

Protein is certainly necessary, for man's tissues contain nitrogen, and only in protein food is nitrogen contained. And since protein contains also carbon, hydrogen, and oxygen, and has usually associated with it the salts requisite for life, one might surmise that it would be quite possible for a man to live on protein alone. Theoretically it should be possible, but no man has ever lived on protein for any length of time; and, though it be theoretically possible, it is likely that any attempt to live on protein alone would fail, since in diabetes a man dies when he ceases to be able to assimulate carbohydrates.

All men include in their dietary all three classes of food, though in different proportions. The Esquimaux diet-sheet consists mainly of protein and fat with very little carbohydrate; the Japanese diet-sheet of large quantities of carbohydrate, a little protein, and very little fat; the Arabs, mainly of protein. Again, as we all know, some men eat twice or thrice as much as other men. And yet on the dietaries so different, qualitatively and

quantitatively, they all seem to thrive. Is there any optimum diet?

One thing is certain, as we said, that there must be a certain amount of protein in the food. How much ought there to be? How much is necessary?

Dietists have tried to find out. They have measured the amount of excretion of nitrogen, and have tried to determine how much protein food is necessary to replace the nitrogen lost. That seemed a very sensible method; but it had its difficulties, since, under ordinary conditions, much of the nitrogen excreted does not come from the tissues at all, but from protein food split up and excreted. However, as the result of many observations and experiments, the conclusion has been reached that in full-grown idle men (not, be it noted, in active men or growing children) nitrogenous equilibrium can be maintained on about an ounce of protein food, which is not a quarter of the amount the average man consumes, and about a quarter of the amount which was formerly supposed to be necessary—provided always that the dietary contains a sufficiency of fat and carbohydrate. Professor Chittenden, of Yale, proved by actual experiment on a number of men of the Hospital Corps of the United States Army that about 60 grammes or 2 ounces of protein per day are all that is required even during hard muscular exercise. Two ounces of protein mean, in terms of food, any one of the following:—½ lb. of lean meat, 9 hens' eggs, ½ lb. of American pale cheese, 1 lb. of uncooked macaroni, 1⅓ lb. of white wheat bread, ½ lb. of dried peas, 10 lbs. of bananas, or 33 lbs. of apples.

For Western meat-eating people who have bacon

and eggs for breakfast, and a lamb cutlet for lunch, and several meat courses for dinner, Chittenden's results seem rather revolutionary; but Eastern people, such as the Japanese, have been on quite as small a protein allowance for centuries.

Granting, then, that a man *can* live and work on 2 ounces of protein a day, we have next to find out how much other food he must eat in addition. Attempts have been made to determine this by determining how much heat and energy a man produces in twenty-four hours, and then determining how much food is required to produce that amount of energy.

As we have pointed out in other chapters, all forms of energy, heat, electricity, and mechanical work are convertible: heat can be turned into electricity, electricity into mechanical work, mechanical work into heat again, and they can all be measured as equivalent to so much heat. Thus every action of the human body can be estimated as so much heat, and together with the heat of the body is the result of the heat produced by the combustion of food. By estimating, then, the heat and work done by the body, we can find out how much food is required to supply the energy.

We estimate heat in Calories (large calories). A large calorie is the amount of heat required to raise 1 kilogram of water 1° Centigrade. In terms of calories we find that

1 gramme of protein has a heat or energy value of 4·1 calories.

1 gramme of carbohydrate has a heat or energy value of 4·1 calories.

1 gramme of fat has a heat or energy value of 9·3 calories.

The heat and mechanical work done by a man can be measured by means of special contrivances and calculations, and, in terms of calories, it has been found that an average man doing an average amount of work produces in twenty-four hours about 3000 calories of energy. All these calories of energy must be provided by the energy of food, and, therefore, an average man should consume for work and heating purposes food of 3000 caloric value.

He must, as we have already said, consume at least 60 grammes of protein, which will provide 240 calories. What additional food is he to take to make up the remaining 2760 calories? Is he to take all or any of it as protein, or is he to take it all as butter, or is he to take bread and butter, or how is he to take it? Suppose he follow Chittenden's advice and take only 60 grammes of protein, then he may make up the 3000 calories in various ways as follows. He can take ½ lb. of beef, and ½ lb. of potatoes, and ½ lb. of bread, and a ½ lb. of butter. Or he can take 2 eggs, 2 pints of milk, ½ lb. of bread, ½ lb. of potatoes, 4 ounces of butter, and 4 ounces of sugar. Or he can take 9 eggs and 2 lbs. of bananas. Or he can take 2 ounces of plasmon and 1 lb. of butter. Or he may refuse to follow Chittenden and make up the calories by eating 4½ lbs. of lean beef. In fact, there is no end to the possible combinations that will produce the necessary calories.

But what sort of combinations are best? Are we simply to provide the calories anyhow, or are there good and bad ways of providing them? No strict rule can be laid down; but all authorities are agreed that both fats and carbohydrates should be included

in the dietary, and that most of the calories should be obtained from carbohydrates.

It must be understood, however, that it is neither quite certain that Chittenden's minimum of protein is best, nor is it certain that a man should take just enough food and no more to supply the heat and work his body produces.

We mentioned that the Japanese had always had only about 60 grammes of protein in their daily food; but of recent years a ration has been fixed for the Japanese army containing 150 grammes of protein and with a fuel value of over 3000 calories, showing that they are of opinion that their old diet contained too little protein and had too low caloric value.

Protein food is particularly appetising and is digestible, even in the absence of appetite juice: it also seems stimulating to the mental faculties, and there is some evidence that it increases the secretion of the substances in the blood which resist microbic disease, and, therefore, it is probable that the diet should contain more than the minimum of protein prescribed by Chittenden, and should be of greater caloric value than the caloric value equivalent to the heat and work produced by the body. It is probable, too, that abundance of protein food in youth not only supplies material for building purposes, but also exercises a stimulating effect on the building process, and that the superior physique of Western nations is due to a diet rich in protein.

Probably the old standard diets of Voit, Rubner, Playfair, and Atwater are not far wrong. They advised that a man's diet should be over 3000

calories in value, and should be proportioned as follows:—

	Protein	Fat	Carbohydrate	Calories
	Grammes	Grammes	Grammes	
Voit	118	56	500	3055
Rubner	127	52	509	3092
Playfair	119	51	531	3140
Atwater	125	125	450	3520

But another thing is to be noted: namely, that there are proteins and proteins, and that vegetable proteins probably have not the same building value as animal proteins. It is possible, of course, to live on vegetables alone: and some vegetarians do so: but in order to obtain the requisite amount of nutriment they have to consume a much greater quantity of food than meat-eaters require to consume, and even after they have obtained the requisite amount of protein carbohydrate and fat, they have greater digestive and assimilative difficulties than meat-eaters. They have greater digestive difficulties, because the nutrient material contained in vegetables is protected to a considerable extent from the digestive juices by the indigestible substance *cellulose*, and they have greater assimilative difficulties because the proteins, even when digested, are not so readily built up into human tissues as are the proteins derived from milk and meat.

We have talked so far of the chemical substances, proteins, carbohydrates, and fats, but we do not take

our nutriment in the form of so many grammes of each; we take our nutriment in the form of foods in which, as a rule, two or three of these chemical substances are contained in varying proportions. Eggs, for instance, contain protein and fat; potatoes contain protein, carbohydrate, and fat. To exactly proportion proteins and carbohydrates in our diet is therefore not easy, nor is exactitude at all desirable. A little too much one day of protein, a little too little another cannot possibly do us harm, and, indeed, it may possibly be better for us than a dietetic dead level of unvarying rectitude.

It will be interesting to look for a moment at the principal foods of man. The principal food of a man for the first part of his life is milk, and at all stages of life milk is a good and a perfect food. It contains all three of the chemical classes of food constituents —proteins, fat in the form of cream, and carbohydrate in the form of lactose, or milk sugar. Milk-protein is one of the best, if not the best, building food we know: it contains practically all the amino-acids necessary for building up the various proteins of the living tissues, whether hæmoglobin, or muscle albumin, or anything else. Milk also contains the substance *lecithin*, which enters into the constitution of the nervous system, and it is interesting to note that human milk contains considerably more lecithin than cow's milk. The moral of this, obviously, is that mother's milk is better than cow's milk for building up the infant's nervous system.

Next in importance to milk may be put the cereals, wheat, oats, maize, and rice. These also contain the three food constituents, proteins, carbohydrates, and fats, and form complete foods on which it would

be quite possible to live exclusively. Of the four, wheat is the most valuable food. Next comes oats, and next maize, while rice, though the staple food of the greater portion of humanity, has the least nutrient value.

After cereals we may put meat. Meat contains protein and fat but hardly any carbohydrate, and, therefore, must be considered a less perfect food than milk or bread; but it would be quite possible to live on meat alone, especially on *fat* meat.

These may be considered the chief foods of man. The proteins, fats, and carbohydrates of milk, bread, and meat are mainly concerned in the building up of his body, and in the making of material capable of conversion into heat and work. But besides these main foods, man consumes potatoes, and eggs, and nuts, and fruits, and snails, and frogs, and edible nests, and honey, and jellies, and many other things, and it would seem to be well that man should have as varied and comprehensive a diet as possible. We do not understand all about diet yet, but we are beginning to understand that diet is not simply a matter of so much protein, and so much fat, and so much carbohydrate; but that there are obscure substances in food that may have a great influence on nutrition.

Quite lately it has been shown that when rice is polished, there is polished away a substance which has been called *vitamine*, and that it is the lack of this substance that causes the disease *beri-beri* in natives fed on polished rice. Quite lately, too, it has been found that whole meal is of more nutritive value than white flour, because

it contains the same substance vitamine. Oatmeal, too, has been found to contain a substance that acts upon the thyroid gland and promotes growth. And there may be many other foods that contain unknown substances that conduce to vigour. It were well, therefore, not to try to live on nuts alone, or vegetables alone, or meat alone; but to have a pretty comprehensive diet-sheet.

It is very extraordinary to reflect that man's brain-cells, and blood-cells, and muscles, and eyes, and teeth, and bones are all made of such things as grains of a cultivated grass, and mutton chops, and red herrings, and apples, and oranges, and potatoes, and green cheese. We put a spoonful of porridge into our mouths, and in a few hours' time it may be part of one of the wonderful cells in the cerebrum: we crunch a nut between our teeth, and in a few hours' time it may be woven into the retina of the eye.

CHAPTER XIII

THE LIVER AND KIDNEYS

The liver is known to most men simply as a scape-goat. Whatever is the matter with a man he puts the blame on his liver. Sometimes he has what he calls a *chill-on-the-liver*, sometimes he says that his *liver is sluggish.* When in doubt he always accuses the liver. Why the liver should be considered more culpable than the pancreas or the spleen, I do not quite understand. But it is so; the blame is always put upon the liver, and the vendors of pills, well aware of this fact, reap a rich harvest from divers liver pills.

Sometimes, no doubt, the liver *is* especially at fault; but probably in most cases it is no more to blame than any other organ. In fact, we cannot pick out an individual organ in this way and lay a disturbance in health exclusively to its charge, as if it led a separate and individual existence. If one thing is certain about the body, it is that all the functions of all the organs work in unison, and that one organ cannot be out of order without producing a general disorder. If the liver be out of order, we may be quite sure that the stomach is out of order, too, and intestinal digestion, and tissue assimilation, and all the other vital processes related to these. In which part of the cycle disorder started it will usually be impossible to say, unless we have evidence, as in lung disease, of local

microbic infection, or, as in cancer, of local tumour; but even then the successful invasion of the microbe and the successful growth of the tumour are quite likely to be the result of a general constitutional disorder.

So far as the liver is concerned, it usually carries out its special functions (which physiologists understand only very partially) in an apparently efficient way. It secretes its bile, it stores up its glycogen as it should, and, if it fail to do so, the results are soon apparent, and not even liver pills can set things right.

The liver is really a most remarkable organ, and deserves much more respect and much more credit then it commonly receives. It is not only the largest gland in the body, but it has greater chemical versatility than any other gland.

It lies in the abdomen tucked up under the right ribs, and has on its under surface the curious little bag of bile known as the gall-bladder. When examined microscopically, it is found to consist of little bunches of cells, each about the size of a pin-head. The little bunches are known as *lobules*, and are tightly packed together in the liver substance so as to give liver its well-known compact structure. The cells that make the lobules are comparatively large: it has been calculated that each contains 300,000,000,000,000 atoms grouped together into 64,000,000,000 molecules.

Through the substance of the liver runs the portal vein which is conveying the blood back from the viscera to the heart, and, as it runs, it divides into branches which divide in turn into a dense meshwork of capillaries that forms a sort

of fine framework for each lobule. The blood thus distributed through the liver by the capillary endings of the portal vein is collected by other veins, known as the *hepatic veins*, which end in the *inferior vena cava*—the great vein that returns the venous blood to the heart. It must be noticed that the portal vein in the liver behaves in a way no other vein behaves: it breaks up into capillaries as if it were an artery, and these capillaries have to be collected again by other veins. It is evident that for some reason or other the venous blood is brought into intimate contact with the cells of the liver. The contact, indeed, is unusually intimate, for the walls of the venous capillaries are imperfect, so that the cells are actually bathed in the venous blood. Under ordinary conditions the tissues of the body are brought into touch with the blood only indirectly through the lymphatics; but in the liver there are no lymphatics, and the blood *actually oozes out of the capillaries so that the cells are soaked in blood.*

Besides the portal vein and accompanying it, there branches through the liver substance another artery called the hepatic artery. This artery is mainly concerned with the nutrition of the walls of the ducts and blood-vessels of the liver.

By the cells of the liver is formed the bile. The bile flows, in the first instance, from the cells into spaces between them, and then into fine branching tubules that run alongside the arteries and veins in the substance of the liver, and ultimately end in the hepatic duct which leads the bile from the liver towards the intestine.

It will be seen from this description that the liver is essentially a dense network of blood-vessels, and bile-vessels, and a conglomeration of little bunches of cells.

Let us look now at some of the functions of the organ.

Its best-known and least important function is the formation of bile. In the opinion of most people, the sole purpose of the liver is to form bile, and to cause biliousness. But bile-making, though it is an item very much in evidence, is really only one minor item of the liver's chemical activity.

The amount of bile formed by the liver every day is surprisingly large, probably as much as two pints. It is a yellowish or greenish fluid containing about 86 per cent. water, and 14 per cent. solids. The solids consist of the bile salts known as sodium glycocholate, and sodium taurocholate, with lecithin, cholesterin, mucin, pigment, and inorganic salts. The bile salts, as the bile flows along the intestine, are mostly absorbed by the intestine and carried back by the portal vein to the liver to be excreted again, and they do not seem to play any important part in the general chemistry of the body. Cholesterin is a very interesting substance: it is found in all living tissues, but especially in the nervous system, and it can be readily extracted from the brain. It is also believed to protect cells against certain toxins.

The bile pigments have no particular use, but they are interesting in that they are formed from the hæmoglobin of red blood-cells. In the liver the hæmoglobin of broken-up red cells is further broken up into iron and pigment. The iron is retained in

the liver, and the pigment is excreted with the bile. The pigment is either yellowish or greenish in colour, and the yellowish pigment turns green when exposed to the oxygen in the air.

Bile has almost no digestive action either on carbohydrates or proteins. Its chief digestive use seems to be to assist the absorption of fat. It effects this assistance in two ways. It dissolves fatty acids, and, by moistening the walls of the intestine, facilitates the passage of the fat through them. When no bile is secreted, fat is very poorly digested.

The bile formed in the liver passes through the hepatic duct which bifurcates and gives it the choice of two directions. It can either pass directly into the duodenum (the first part of the intestine), or it can pass into the gall-bladder and lie there till required. In the intervals between digestion, the bile takes the second route and accumulates in the gall-bladder; but during active digestion, the gall-bladder is emptied and all the bile formed passes straight into the intestine. During active digestion, too, and just after the chyme passes into the duodenum, the bile flows more copiously; and this copious flow seems to be stimulated, as the pancreatic juice is stimulated, by the formation and absorption of *secretin* produced by the action of the acid chyme on the cells of the mucous membrane of the duodenum.

When there is obstruction to the passage of bile, the bile enters the blood, and is carried over the body, giving a yellow tint to the skin and mucous membranes.

The most important function of the liver is its

glycogenic function, or, in other words, the power of forming and storing the starch-like substance, called '*glycogen*,' from the glucose and amino-acids supplied to it by the portal vein. From amino-acids little glycogen is formed, but from glucose it is formed in large amounts, so that after a carbohydrate meal 12 per cent. of the weight of the liver is found to consist of glycogen. This glycogen remains stored in the liver till the tissues require sugar, and it is turned into glucose again and sent to the tissues just as they require it. The liver, therefore, may be considered the Sugar Bank of the body.

If an animal be starved and worked hard, this reserve fund of glycogen in the liver is soon exhausted, for it is the first fund to be drawn upon in case of emergency.

Under normal conditions, however, the liver gets as much sugar as it gives, and keeps the proportion of sugar in the blood at the level necessary to supply the muscles and other tissues with the amount they require for heat and energy.

The liver, therefore, not only makes bile, but it stores glucose as glycogen and turns the glycogen into glucose again, according to the requirements of the tissues. If more carbohydrate be given than the liver can hoard as glycogen, and than the muscles and tissues can use as glucose, then a certain amount of sugar is discharged by the kidneys, and we have a condition that is called *alimentary diabetes* or *alimentary glycosuria*. The amount of glycogen the liver can store, and the amount of glucose the tissues

can assimilate, vary in different individuals, and, therefore, different amounts of carbohydrate are necessary in different individuals to produce alimentary glycosuria. In some people a very small over-indulgence in carbohydrate food will lead to glycosuria, and in others glycosuria is almost impossible to produce. As a rule, a man can take six ounces of glucose without any discharge of sugar in his urine. Alimentary glycosuria is not a serious disorder: it is easily remedied by reducing the carbohydrate in the diet.

The sugar that appears in the urine in true diabetes is a much more serious thing. It is due neither to disease of the liver nor to disease of the general tissues; but to disease of the pancreas, the gland in the abdomen that, as we have seen in the last chapter, performs such good digestive work. It continues to secrete quite healthy and efficient pancreatic juice, but it fails to add to the blood some substance which enables the muscles and other tissues to assimilate the sugar in the blood. The blood carries the sugar to the tissues: but they cannot use it, or can use it only to a very slight extent, and so it accumulates till it is removed by the kidneys.

If the pancreas be removed from an animal, diabetes at once follows: the tissues of the animal are unable to assimilate sugar, and the accumulating sugar leads to glycosuria.

A very interesting experiment has been performed showing the relationship between the pancreas and the assimilation of sugar. A normal heart cut out of the body will assimilate sugar, if blood containing sugar be passed through

its blood-vessels. If, however, the heart be a diabetic heart it will fail to assimilate the sugar, but if a little decoction of fresh pancreas be added to the blood, then the diabetic heart will assimilate sugar almost as well as the healthy heart.

Does not this show the wonderfully complex relationship between the various tissues and organs of the body? The saliva and the pancreatic juice make the sugar called glucose out of carbohydrates, and the liver stores any surplus glucose in the form of glycogen; but all these arrangements prove futile unless the pancreas have added to the blood that flows through it, some mysterious unknown substance which enables the tissues to make use of the sugar.

We have mentioned the bile-forming and glycogen-forming functions of the liver; but even yet there are other functions to mention. The liver not only forms bile and glycogen but it also prepares fats for the use of the tissues, so that the tissues can oxidise them. Here again, however, it would seem to require the assistance of the pancreas, for in diabetes the tissues are unable completely to oxidise the fats, with the result that poisonous acids accumulate in the blood and produce a dangerous condition known as *acidosis*.

The liver not only prepares fat for oxidation by the tissues, it also builds up complex fats containing phosphorus, known as *phosphatides*, which form important constituents of the nervous system. To sum up, then, the liver forms bile, transforms glucose into glycogen, transforms

glycogen into glucose, prepares fat for oxidation by the tissues, and builds up complex fats. These little cells in this big organ perform all these different complicated chemical operations. Not only so, but in the course of their chemical operations they produce a great part of the heat that maintains the body at a temperature of 98·6° Fahrenheit, and they prepare the amino-acids for use in the tissues by converting their nitrogenous portion into urea, and they also destroy excess of uric acid and save us from gout. And yet people think they can regulate and correct the functions of the liver by liver pills!

The kidneys compared with the liver are quite pigmy glands. They are only a few inches in length and weigh only about a quarter of a pound each. But they are essential to life and have quite intricate structures, and quite complex functions.

A kidney consists essentially of a multitude of very fine tubules which conduct fluid from the blood into a larger tube called a *ureter*, that finally opens on the surface of the body. When we examine microscopically a single one of the fine kidney tubules, we find that it begins in a little sac. For some distance from the sac it is much bent and convoluted. Finally, it ends in a straight limb that opens into the ureter. The sac is called Bowman's capsule, and inside it is a bunch of capillaries. To be correct, they are not exactly inside it but are dinted into it much as we can dint our finger into a soft indiarubber ball. The capillaries are endings of branches of the renal artery, and they have unusually thin walls. The capillaries unite again into a small vessel, which issues from

the capsule only to break up into capillaries again, which ramify over the convoluted part of the tubules and finally are collected into a vein. It will be thus seen that the blood supply of the kidney is very peculiar. The function of the capsule and tubule is to take water and certain solids from the blood, and to discharge them from the body. Arterial blood enters the kidney, water and certain substances are abstracted from it, and then the blood passes onward to the heart.

The abstraction of water and other substances from the blood is, to some extent, merely a filtration. The walls of the capillaries in the capsule are very thin, the pressure of the blood in them is considerable, and the result of the pressure alone must account for a certain amount of exudation, but it is more than a simple process of filtration. For the cells in the capsule exercise a selective influence; in health they do not permit albumin to pass through; and they do not permit sugar to pass through unless, as in diabetes, it is present in excess. As the fluid passes down the tubules a certain amount of water is reabsorbed by the cells which line the convoluted parts of the tubule, and so the fluid is concentrated. Not only so, but the important substance *urea* is added to the fluid at this point by a process of actual excretion on the part of the cells lining the convoluted tubules, and a new substance not present in the blood, called *hippuric acid*, is formed and added.

The fluid finally secreted or excreted into the ureters contains no sugar, no albumin, 1·2 per cent. of common salt, 2·0 per cent. of urea, 0·05

per cent. of uric acid, 0·07 per cent of hippuric acid. Its colour is due to the bile pigments manufactured by the liver out of red blood-cells. In cases of jaundice it may be dark brown, greenish, or almost black. Health is possible with only one kidney; but if both kidneys are cut out death occurs in a few days.

The quantity of fluid taken from the blood by the kidneys usually amounts to about 2½ pints a day; but the quantity varies with the amount of fluid drunk and with the activity of the sweat glands. The solid matter in the fluid amounts to about two ounces a day.

The most interesting solids are the urea and uric acid. Both are formed by the liver, the former is the nitrogenous residue of amino-acids, the latter is formed from the nuclei of broken-down cells. Uric acid is formed in excess in gout, and then gravel and stones are apt to be formed, and salts of uric acid are apt to be deposited in the cartilages of the joints, especially in the cartilage of the joint of the great toe. We have said that the kidney cells do not allow the passage of the albumin in the blood; but when the kidney cells are damaged, as in Bright's Disease, albumin passes out with the fluid—a condition known as *albuminuria*. After violent muscular exercise there also may be a little albuminuria, but the condition in this case is quite transitory and not serious.

CHAPTER XIV

SPLEEN, THYROID, THYMUS, LYMPHATIC GLANDS, SUPRA-RENALS, PITUITARY BODY

The public attach great importance to a few organs in the body. They realise that the brain, and heart, and lungs, and kidneys are essential to existence, but they are inclined to ignore almost altogether such organs as the spleen, and the lymphatic glands, and the thyroid, and the supra-renal gland, and the pituitary body. Yet these glands, too, are essential for the welfare of the body: they perform interesting and necessary functions and cannot be ignored. Now we shall briefly consider them.

Let us begin with the spleen. The spleen is an organ which has had rather a bad reputation. It has been blamed for bad temper, and other moral defects; and we still talk of splenetic outbursts of temper, and suggest that a man is suffering from the spleen when he shows an unpleasant and uncharitable disposition. It is rather strange how this idea came about. Perhaps it was based on the irritable temper of those suffering from enlarged spleen in the old days when malaria was prevalent. Anyhow, the idea has no foundation; the spleen has really little or nothing to do with the temper, and it is really a very useful and almost essential organ.

The spleen is tucked up under the lower ribs on the left-hand side. In structure it is like a fine sponge-work, and the meshes of the sponge-work

are packed with white blood-cells intermixed with larger white cells, and with cells like red blood-cells. The organ is supplied with blood by the splenic artery which enters the meshwork, and first divides into small branches and then into capillaries; and the capillaries are actually continuous with the interstices of the meshwork, so that the blood actually fills all the pores of the spleen and soaks the cells they contain. The interstices, again, are continuous with capillaries that join into veins. So that the spleen may be compared to a kind of sponge interpolated in the course of the capillary circulation.

The meshwork of the spleen is made of connective tissue, and also of muscular fibres, and all life long it contracts and relaxes, and so drives the blood through it, just as if it were a little heart. The contractions are under the control of the nervous system.

Now what is the function of the organ? It has at least two functions—two very important functions. It destroys worn-out red blood-cells, and it forms new white blood-cells.

When the cells in the meshes of the spleen are carefully examined, they will be found to be full of little brown particles which are fragments of red blood-cells, and little specks of pigment, which are the pigment of red blood-cells. There can be no doubt, therefore, that the spleen breaks up worn-out red blood-cells.

There can be no doubt, too, that the spleen adds new white blood-cells to the blood, since the blood leaving the spleen by the splenic vein is richer in white blood-cells than the blood than

enters the spleen by the splenic artery. In some cases, also, the spleen destroys or at least captures germs. In recurrent fever, for instance, the white cells of the spleen are found to be full of the cork-screw-like micro-organisms that cause the disease.

It is possible, also, that the spleen not only destroys old red blood-cells, but also forms new ones.

The Lymphatic Glands.—Lymphatic glands might be called miniature spleens, they are constructed on very much the same plan as the spleen, and perform somewhat the same functions. They vary in size from the size of a hempseed to the size of a large bean, and each consists essentially of a meshwork packed with white cells. The meshwork, however, contains no muscular fibres, and so the glands do not contract, and the meshwork is interpolated in the couse of a lymphatic, and not in the course of a blood-vessel. The glands are found in great numbers all over the body, but especially in the neck, groin, and armpit, and along the course of the great vessels of the abdomen and chest. When they are enlarged they can be easily felt in the neck and elsewhere.

They do not destroy red blood-cells like the spleen; but, like the spleen, they form new white blood-cells and catch and destroy microbes and cancer-cells.

The lymphatic glands often arrest tubercle bacilli which may be in the lymph flowing through them, and unless they succeed in extirpating the bacilli they become diseased and may suppurate. Suppurating glands of this sort used to be called scrofulous glands.

Likewise when the glands arrest cancer-cells they become hardened and cancerous.

The Thyroid Gland.—The thyroid gland is a soft gland, rather like sweet-bread in appearance, which lies in front of the neck, below Adam's apple. It consists of two lobes, right and left, connected by an isthmus. The gland is made up of little round sacs lined with clear cells, and is richly supplied with blood-vessels. Inside the sacs is a transparent jelly-like material called *colloid.* The gland is richly supplied with blood.

For a long time the function of this gland was quite unknown; but, eventually, it was discovered that the gland performs very important functions, and that the diseases known as *myxœdema* and *cretinism* are due to atrophy or inaction of the gland. In the adult, inaction causes myxœdema, and in young children inaction causes cretinism; but in both cases the cause is the same—thyroid inefficiency.

The disease, myxœdema, caused in the adult by thyroid deficiency, is a very distressing disorder. It is described thus by Dr G. A. Gibson:

'It is earliest observed in the face, which gradually acquires a stupid, heavy, apathetic, swollen look. All the features become coarsened, swollen, and enlarged; the lower eyelids have a baggy look, the upper eyelids are swollen and hang down over the eyeballs; the cheeks are pendulous, the nose is broadened, and the lips and chin coarsened. . . . The hair of the scalp and eyebrows falls out. . . . The subcutaneous swelling gradually spreads to the root of the neck, and appears in the abdomen, hands, feet, and other

parts, giving the person a clumsy, bulky appearance. The gait is deliberate, waddling, and awkward, and no movement of any kind is performed nimbly and neatly. The hands become more square in shape, or "spade-like," owing to the fingers being swollen and non-tapering, and they are used clumsily; the feet also become swollen, and larger gloves and boots are required. The soft tissues of the mouth, throat, and larynx also become infiltrated, hence the tongue is enlarged, swallowing may be slightly interfered with, and the tones of the voice become thick, harsh, and monotonous. . . . The hair, nails, and teeth all suffer greatly from malnutrition, the two first becoming dry and brittle, the last carious and loose. . . . There is marked muscular weakness. The nervous system is very distinctly affected. . . . There is great deliberation both of speech and movement, and a disinclination for mental and bodily exertion. Memory becomes weakened, ideas are very slowly grasped and responded to, and there is sometimes an overpowering tendency to sleep at odd times. . . . One or all of the special senses may be dulled. Most patients are contented and good-natured, not to say apathetic, but occasionally a morose unsocial temper is developed, or depression, delusions, and mental alienation may ensue.'

That is a terrible picture of a terrible disease produced by the inactivity of a little gland in the neck. There is no doubt at all that thyroid deficiency is the cause, for exactly the same symptoms can be produced by cutting out the thyroid gland.

The nature of the disease suggested a remedy. Surgeons grafted a thyroid gland and injected thyroid extract under the skin of myxœdematous patients, and found that the symptoms disappeared. Finally, it was discovered that the gland, raw or cooked, was equally efficacious, and so a simple cure was found for the dreadful disease.

The effect of thyroid extract in these cases is marvellous. The patient's mind lights up again; memory is restored; his speech becomes normal and distinct; his muscular activity returns; the thickening under the skin and mucous membrane disappears, so that figure and features regain their normal aspect: the hair grows again; in fact, practically all symptoms of the disease vanish.

The disease called *cretinism*, produced by the atrophy of the thyroid gland in the young child, is even more terrible than myxœdema. The skeleton of such a child soon ceases to grow, and the mind fails to develop. A cretin of adult age remains a child—an idiotic, hideous child, pot-bellied and stunted.

Here, again, by the administration of thyroid gland by mouth, the disease can be cured. An ugly and idiotic child can be converted into a pretty, bright child of ordinary intelligence and normal powers of growth.

Sometimes the gland is over-active and hypertrophied, and then a disease called *exophthalmic goitre* appears—a disease characterised by bulging eyes, great nervousness, rapid pulse, wasting and muscular weakness. By excising part of the gland this disease can be also cured.

It is a very remarkable thing that mind and body

should be so much at the mercy of this gland. Let a child be born with the mental potentialities of a Shakespeare, with the bodily strength of a Samson, yet if this little mass of cells fail to do its duty, the child will become a hideous, deformed, dirty idiot. Let the gland fail to act in a strong, active, clever man and he grows coarse, and dull, and sluggish in mind and body.

As we mentioned in another chapter, there seems to be some substance in oatmeal that stimulates the thyroid gland, and therefore oatmeal ought to be specially good food for growing children.

Thymus Gland.—Another gland in the neck is the thymus gland. It is essentially a gland of early childhood. It attains its greatest size soon after birth; and after the second year gradually diminishes in size till in adult life only vestiges remain. In structure it is built up on the plan of lymphatic glands—a meshwork with white cells in the meshes. Its function is not known, but there seems some evidence that it has some effect on the development of the reproductive organs.

Supra-Renal Bodies.—The supra-renal bodies are two triangular or cocked-hat shaped bodies, set like little caps on the tops of the kidneys. Each consists of an outer sheath or jacket of connective tissue, and a connective tissue meshwork, containing groups of cubical cells. In the centre of the body there are coarse fibrous tissue, numerous blood-vessels, and numerous nerve fibres and altered nerve-cells. The cells of the outer part or *cortex* of the bodies contain lecithin. The nerve elements of the central part or medulla are an outgrowth from the sympathetic nervous system.

The supra-renal body is a very insignificant-looking object, and for long it was not known to play any important part in the economy of the body; but in 1855 Dr Addison pointed out that degenerative destruction of these bodies was associated with great muscular weakness, loss of vascular tone, vomiting, and nervous prostration, together with a peculiar bronzing of the skin. This combination of symptoms associated with disease of the supra-renal bodies has since been known as *Addison's Disease.* This disease is almost always fatal.

When the bodies are experimentally removed or destroyed, there always follow great prostration, muscular weakness, and death within twenty-four hours.

Twenty years ago it was discovered that extract of the supra-renal bodies when injected into the circulation causes a constriction of all the blood-vessels in the body, with a consequent very great rise in blood-pressure. Later on a Japanese scientist, Takamine, succeeded in isolating the active substance and called it *adrenalin*, and chemists have since prepared it artificially.

Adrenalin is an immensely potent chemical substance, and a very minute dose by injection suffices to raise the blood-pressure.

It would seem certain, therefore, that the supra-renals maintain the tone of the arteries of the body by forming this substance, adrenalin, and throwing it into the blood; and the lowered blood-pressure that follows extirpation or disease of the supra-renals is due to lack of adrenalin in the blood. There is no doubt that they also maintain the tone of both the voluntary and involuntary muscles.

But adrenalin has many other actions: it makes the hairs of the head stand on end, it dilates the pupil, it causes a flow of saliva. In a general way it seems to promote all the functions of the sympathetic nervous system.

These little insignificant caps, then, set on the tops of the kidneys, play very important parts in the functions of the body, and indeed are essential to its life—another proof of the unity and interdependence of all the organs and tissues of the body.

Pituitary Body.—Finally, let us look for a moment at the tiny gland known as the pituitary body. It is a little double gland with anterior and posterior lobes lying within the skull under the cerebrum. It is smaller and more insignificant even than the supra-renal bodies; but it also is essential to life. If it be totally removed, or if the anterior lobe be removed, death follows in a few days. Partial removal of the anterior lobe produces adiposity and atrophy of the organs of generation. Injection of extract of the anterior lobe will keep an animal alive after extirpation of the whole gland or of the anterior lobe, and will preserve the health of the animal if the anterior lobe be partially removed.

The anterior lobe throws some substance into the blood which promotes the growth of the skeleton of animals; for if young animals are fed on it their skeleton grows more rapidly, and an overgrowth of the lobe produces the overgrowth of the bones of the face and limbs known as *acromegaly.*

The posterior lobe has quite a different effect. It has no effect upon bone-growth at all; but if extracts of it are injected into the circulation it causes a rise in blood-pressure, a slowing of the heart, a

contraction of various involuntary muscles, and an increase in milk secretion.

All these glands, then,—spleen, lymphatic glands, thyroid gland, supra-renal bodies, and pituitary body—play most interesting, important, and more or less mysterious parts in the economy of the body, and teach us what a wonderful and mysterious organism the body is. Who would have imagined that a tiny gland within the skull would influence the growth of the skeleton? Who would have thought that disease of the little supra-renal caps of the kidney would produce a bronzing of the skin? Who would have thought that a little deficiency of thyroid secretion in the blood would produce myxœdema and cretinism. Yet so it is!

CHAPTER XV

HEREDITY

Thou not cast'st us new
Fresh from thy craftship, like the lilies' coats,
But foists us off
With hasty tarnished piecings negligent,
Snippets and waste
From old ancestral wearings
That have seen sorrier usage; remainder flesh
After our fathers' surfeits; nay, with chinks,
Some of us, that if speech may have free leave
Our souls go out at elbows.'

FRANCIS THOMPSON.

'With antecedents
With my fathers and mothers, and the accumulations of past years—
With all, which had it not been, I would not be here as I am.'

WALT WHITMAN.

What is the nature of heredity? How does it come about that children inherit some characters from their fathers and some characters from their mothers, and some characters from remote ancestors? How does it come about that man is composed in such a mosaic fashion? What regulates the inheritance of the characters?

The persistence with which some little isolated features and traits are transmitted is very extraordinary. Professor J. Arthur Thomson quotes various instances of such persistent transmission of trivial details.

'A gentleman had a peculiar formation of the right eyebrow. It was strongly arched, and some of the hairs in the centre grew upwards. Three of his sons have the same peculiarity; one of his granddaughters has it also; so has his great-granddaughter; and if we are to believe the artists, this gentleman's grandfather and great-grandfather had the same peculiarity.'

'A woman with blonde hair, a birthmark under the left eye, and a lisp, married a man with dark hair and normal utterance. There were nineteen children, none of whom showed any of the mother's characters. Nor among the numerous grandchildren was there any trace. In the third generation, however, there was a girl with blonde hair, and mark below the left eye, and a lisp.'

The last instance shows not only that detailed characters may persist, but that they may persist in a latent condition for generations and then reappear again.

How are we to explain such facts?

We have seen, in the first chapter, that the fertilised ovum or *zygote* is formed by the conjunction of the sperm of the male and the ovum of the female, and it is, therefore, to be expected that the offspring should inherit both characters of its father and characters of its mother; but how does it come that it may inherit also characters of far-back ancestors which neither the father nor the mother show?

The first satisfactory theoretical explanation of the leading facts of heredity was offered by Weismann. His theory is known as the theory of the *continuity of the germ-plasm,* and is full of

interest. Weismann holds that the characters that are found in a grown organism are contained in particulate form in the chromosomes of the male cell and the female cell that join to form the zygote. He names the representative particles *determinants*, since they determine what the child is to be, and the whole mass of them he calls the germ-plasm. This, of course, would explain how a child is made up of bits of its father and mother; but how about other further-back ancestors—how do they come to find a place in the mosaic of the child? Ancestral characters, says Weismann, appear in the child because the germ-plasm has not been formed by the parent, but is part of an original germ-plasm that has been handed down from generation to generation.

When the germ-plasm of the ovum is developed into a child, part of the germ-plasm is set aside to form the germ-plasm of the child. Thus the germ-plasm of a man or woman (sperm or ovum) is just the same germ-plasm as the germ-plasm of the father and mother that grew into the man or woman; and the germ-plasm of the father and mother is just the same germ-plasm as the germ-plasm of their fathers and mothers, and so on as far back as we can go.

In Weismann's own words: 'In each development a portion of the specific germ-plasm which the parental ovum contains is not used up in the formation of the offspring, but is reserved unchanged for the formation of the germinal cells of the following generation.'

Professor J. Arthur Thomson puts it very clearly: 'If a fertilised egg-cell have certain

characters a, b, c, x, y, z, it develops into an organism in which these characters a, b, c, x, y, z, are expressed; but, at the same time, the future reproductive cells are early set apart, retaining the characters a, b, c, x, y, z, in all their entirety to start a new organism again with the same "capital."'

This statement by Professor Thomson, however, is not *quite* correct. The fertilised egg-cell may have the characters a, b, c, x, y, z, but it by no means follows that in the organism developed from the egg-cell, the characters a, b, c, x, y, z, will be *expressed*. On the contrary, some will be expressed and others repressed, and it is the fact that characters may be present, yet unexpressed, that explains how ancestral characters that have not appeared for generations suddenly re-appear.

The theory of the continuity of the germ-plasm throws a flood of light on the transmission of characters and the nature of heredity. It represents reproduction in quite a new aspect.

No individual produces germ-plasm, but germ-plasm, continuous as the runner of a strawberry plant, produces individuals, a little being reserved in each individual for further reproductive purposes. The offspring, on this theory, inherits nothing from the bodies of its parents, and the likeness between offspring and parent is due merely to the fact that it is made from pieces of the same germ-plasm as made its parents. It resembles a parent because it is a chip of the old block, and it varies from a parent because to chop is to change.

Let us see what amount of likeness and what

amount of variation we are to expect. The father is a product of certain germ-plasm containing certain determinants, and the mother is the product of certain germ-plasm containing certain determinants. In the process of maturation and fertilisation, as we have seen in the first chapter, the ovum loses one-half of its chromosomes—loses, that is to say, one-half of the stock of determinants that determined the development of the mother, and the sperm loses one-half of its chromosomes—loses, that is to say, one-half of the stock of determinants that went to the making of the father. Therefore the conjoint fertilised ovum or *zygote* contains one-half of the determinants that were in the germ-plasm that went to the making of the mother, and one-half of the determinants that were in the germ-plasm that went to the making of the father. The blend, therefore, is not a blend of mother and father, but a blend of so much of the mother and so much of the father.

Now it is quite plain that ovum and sperm, when they join, must each still contain determinants of every part of a complete organism, in spite of the moiety of determinants each has ejected. This must be so, otherwise it would be impossible to ensure the production of perfect offspring. Each has determinants of eyelashes, and teeth, and nails, and brain-cells, and so on. Therefore, in the building up of the offspring from the ovum there must be competition between the maternal and the paternal determinants, and the result must be that either the one or the other prevails, or that they blend together, or that they

neutralise each other, or that in alliance they result in new characters. This is exactly what we see: we see in the offspring certain maternal and certain paternal characters re-appearing, and we see other characters that are plainly a blend between the maternal and paternal qualities.

But it must be clearly understood that no child's mosaic is made up simply of paternal characters, and maternal characters, and of characters a blend between the two.

In the first place, the rejection of paternal and maternal determinants at maturation must very much alter the sum of characters contained in the germ-plasm of the sperm and in the germ-plasm of the ovum. In the second place, all the determinants in the original germ-plasm of the father were not *expressed* in the father, and all the determinants in the original germ-plasm of the mother were not *expressed* in the mother. Characters that were expressed in grandparents and great-grandparents, and that were unexpressed in the father and mother (though still present as determinants in their germ-plasms), may be expressed again; and characters expressed in father and mother may be repressed (though still present as determinants in the germ-plasm).

There is thus great room for variation, though the chances are that most of the characters in a child will reproduce characters of one or both parents, though mixed with these will appear new characters and will reappear ancient characters latent in the parents.

In the following passage Galton gives a very good idea of this mosaic conception of heredity. 'Many of

the modern buildings in Italy are historically known to have been built out of the pillaged structures of older days. Here we may observe a column or a lintel serving the same purpose for a second time, and perhaps bearing an inscription that testifies to its origin, while as to the other stones, though the mason may have chipped them here and there, and altered their shape a little, few if any came direct from the quarry. . . . This simile gives a true though rude idea of the exact meaning of particulate inheritance—namely, that each part of the new structure is derived from the corresponding piece of some older one, as a lintel was derived from a lintel, a column from a column, a piece of wall from a piece of wall. . . . We appear to be severally built up out of a host of minute particles of whose nature we know nothing, any one of which may be derived from any one progenitor, but which are usually transmitted in aggregates, considerable groups being derived from the same progenitor. It would seem that while the embryo is developing itself, the particles more or less qualified for each post wait, as it were, in competition to obtain it, also that the particle that succeeds must owe its success partly to accidents of position, and partly to being better qualified than any equally well-placed competitor to gain a lodgment. Thus the step to step development of the embryo cannot fail to be influenced by an incalculable number of small and mostly unknown circumstances.'

From a statistical study of the inheritance of colour in pedigree basset hounds, Galton tried to discover in what proportion ancestors contributed characters to their offspring, and in 1897 he

enunciated the following law, known as the *Law of Ancestral Heredity*:—

'The two parents between them contribute, *on the average*, one-half of each inherited faculty, each one contributing one-quarter of it. The four grandparents contribute between them one-quarter, or each of them one-sixteenth, and so on, the sum of the series $\frac{1}{2}+\frac{1}{4}+\frac{1}{8}+\frac{1}{16}$ . . . being equal to 1, as it should be . . .'

Galton pointed out that 'this law is strictly consonant with the observed binary subdivisions of the germ-cells, and the concomitant extrusion and loss of one-half of the several contributions from each of the two parents to the germ-cell of the offspring.'

Karl Pearson endeavoured to find the law of ancestral contributions by biometric calculations, and found the proportional contributions of parents, grandparents, and great-grandparents to be 0·6244, 0·1988, and 0·0630 respectively—proportions agreeing very well with the proportions fixed by Galton.

No doubt some such proportions obtain; but it is impossible to draw such a distinct line between paternal and pre-paternal contributions, since, as we have seen, the germ-plasm is continuous.

All theories of heredity have been wont to draw a distinction between acquired and innate characters, and the question has been much debated whether acquired characters are transmitted. At one time the transmission of acquired characters was almost universally held. Lamarck, the pioneer of modern theories of evolution, held that 'all that has been acquired or altered in the organisation

of individuals is conserved by generation, and transmitted to the new individuals born of those that have undergone their change. In this way many things could be explained. One could explain the long neck of the giraffe by the fact that successive generations of giraffes each lengthened their necks an inch or two by stretching for leaves, and that each generation transmitted extra inches to their descendants. One could explain the fleetness of the deer by the fact that successive generations of deer acquired extra speed by their efforts to outstrip their enemies, and transmitted the extra speed to their offspring.' Lamarck thus explained the elongation of snakes: 'The snakes sprang from reptiles with four extremities, but, having taken up the habit of moving along the earth and concealing themselves among bushes, their bodies, owing to repeated efforts to elongate themselves and to pass through narrow spaces, have acquired a considerable length out of all proportion to their width. Since long feet would have been very useless, and short feet would have been incapable of moving their bodies, there resulted a cessation of use of these parts, which has finally caused them totally to disappear, although they were originally part of the plan of the organisation of these animals.'

Assuming evolution to be a fact, such a principle of progressive growth was a very useful explanation of the evolutionary process, and both Darwin and Spencer accepted the doctrine of the transmission of acquired characters, and used it to support the theory of evolution.

But now that we understand the relationship between germ-plasm and the body,—now that we understand that the germ-plasm is continuous, and is the source of bodies not the products of bodies—now we understand, too, that acquired characters are not transmitted and cannot be transmitted. The blacksmith's arm, a product of germ-plasm, may be developed to any extent; his son's arm will not be the least stronger on that account: it will depend on determinants in the parental germ-plasm which was existent long before parents and son, and is unaffected by any athletic exercises. The giraffe may stretch its neck with the utmost determination, but the length of its offspring's neck will be determined by determinants in the germ-plasm that existed long before either parents or offspring, and is uninfluenced by any extensions of the parent's neck.

The question, however, *Are acquired characters transmitted?* is a very misleading statement of the problem. In a sense all characters are acquired. The power of standing is acquired, the ordinary development of muscles is acquired, the power of buttoning a button is acquired; the bald head of old age is acquired, the loss of milk teeth is acquired. Yet no one doubts that all these, and all the other ordinary structural and functional acquisitions of the body, are transmitted. The real question is whether the parents are capable of transmitting any characters they have acquired to their offspring, so that the characters will appear in the offspring at a more advanced stage of development than they appeared in the parents, or so that they will be more readily or

quickly developed. The answer to that question is an unqualified negative. The parents may button gloves all their lives, and no doubt will transmit to their offspring the powers of muscular co-ordination that make glove-buttoning possible, but the offspring will learn no more readily than the parents the art of buttoning gloves because of the parents' assiduous practice.

Parents transmit to their offspring the determinants of characters they possess, and the characters begin in the children as in the parents as determinants, and require just the same conditions—exercise, or heat, or food, as the case may be—for their development. The development or non-development of any structures or functions in the parent have no effect on the offspring. All that matters to the offspring is the germ-plasm that goes to its making, and the germ-plasm, as we have said, is much older than the parents, and produced them and is unaffected by their development.

The only way in which the germ-plasm can be affected by the body containing it is nutritionally. Like all other living matter it requires air and food. It may be well nourished or badly nourished, and it may be fed with pure or with impure blood. Certain diseases and certain poisons, then, are detrimental to the germ-plasm; but no development of the functions and structures of the body containing it can in any way stimulate or direct its developmental capacities.

CHAPTER XVI

MENDELISM: THE DETERMINATION OF SEX

In the middle of the last century some very important light was thrown upon the problems of heredity by a German priest, Gregor Johann Mendel.

Mendel experimented with peas in his cloister gardens, and discovered some very illuminating facts. His experiments consisted in crossing peas differing in certain definite comparable characters, and noting the characters of the hybrid peas and of interbred hybrid peas.

He found that the hybrids showed only one of two contrasted characters. Thus when he crossed tall and dwarf peas the result was not some tall peas and some dwarf peas, but all the peas were tall. He called the character that ousted the other character, the *dominant* character, and the character that failed to appear, the *recessive.* Thus, in the case we have cited, the tallness was the dominant, and the dwarfness the recessive, character.

When he interbred the hybrids, he found that the recessive character reappeared again in one in every four of the next generation. His words are as follows:—'In this generation (the first generation bred from the hybrids) there reappear, together with the dominant characters, also the recessive ones with their peculiarities fully developed, and this occurs in the definitely expressed average proportion of three to one, so that among each four plants of this generation, three display the dominant character and one the recessive. This

relates, without exception, to all the characters which were investigated in the experiments. . . . Transitional forms were not observed in any experiment.'

Having ascertained this fact with regard to the hybrids, Mendel next proceeded to inter-breed the dominants and the recessives of the first offspring of the original hybrids. He found, as a result of such experiment, that the recessives gave rise only to recessives; but he found that two-thirds of dominants behaved like the original hybrids, and gave rise to one recessive in every four. The remaining one-third of the dominants produced only dominants.

The first offspring, therefore, of the first hybrid generation were found on inter-breeding to consist of twenty-five per cent. pure recessives, twenty-five per cent. pure dominants, and fifty per cent. hybrid or impure dominants.

The following table shows the facts we have just been detailing:—

Plant with yellow seeds dominant | Plant with green seeds recessive

Hybrids with yellow seeds

Hybrids with yellow seeds | Hybrids with yellow seeds

1 plant with yellow seeds (pure) — interbred — yellow — yellow

2 plants with yellow seeds (hybrid) — interbred — 1 yellow (pure) | 2 yellow (hybrid) | 1 green (pure)

1 plant with green seeds (pure) — interbred — green — green

Mendel next proceeded to investigate more complicated combinations: he proceeded to cross hybrid peas with *pairs* of contrasted characters. For instance, he crossed peas with round yellow seeds with peas with wrinkled green seeds. In such a case he found that all possible combinations were formed. In the instance we have taken of the peas—round yellow, and wrinkled green, and wrinkled yellow, and round green peas were produced. He found, too, that in every case the varieties were produced in definite ratios to each other.

Mendel was not contented with the discovery of the facts: he sought also to explain the facts, and suggested an explanation that is commonly accepted. He suggested that the ratios could be explained by assuming that the determinants of all the contrasted characters were represented in the reproductive cells (egg-cells and pollen-cells of the plant), but in such a way that members of pairs of contrasted characters were never together in the same cell, and that members of pairs of contrasted characters were present in equal numbers.

Assuming this to be the case, then, if during fertilisations the egg-cells and pollen-cells conjoined at random, the conjunctions would produce the ratios of pure breeds and of hybrids that he had found.

This is rather hard to follow, but take a simple case.

Let us take the case we have already considered of a hybrid pea (a cross between a pea with yellow seed and a pea with green seed) with yellow seeds.

Each unfertilised seed of the pea will contain

either a yellow or a green determinant, but not both. So also each pollen grain of the pea will contain either a yellow or a green determinant, but not both. If, then, pollen grains alight by chance on seeds and fertilise them, the result will be that a yellow determinant in the pollen will join in the seed a green and yellow determinant alternately, since there are equal chances of alighting on either; and a green determinant in the pollen will also join in the seed a green and yellow determinant alternately. The yellow determinant in the pollen will thus form one all yellow and one yellow-green seed, and the green determinant in the pollen will form one all green and one yellow-green seed, or one pure green, one pure yellow, and two impure or hybrid yellow: which is just the very ratio in which they were found by Mendel.

The principle may be well illustrated as follows:—Let two bags, each containing forty yellow and forty green balls well mixed, be taken, and let a ball be drawn by chance out of each bag and the two balls be put together. It will be found when all have been paired that there are about forty pairs both green, forty pairs both yellow, and eighty pairs one green and one yellow,—again, just the Mendelian ratio.

The explanation supposes merely a certain segregation and separation of the determinants of contrasted characters and then random conjunction, when the result, according to the law of averages, will be the ratios found.

We have taken a simple case, but the same explanation is good for the ratios found in hybrids with two or more contrasted characters in their composition.

Suppose we cross a tall purple pea and a dwarf white pea. Then, according to theory, the hybrid will have all contrasted characters equally represented in its seed and its pollen grains, but no two contrasted characters in the same seed or pollen grain. It will not have tall dwarf seeds, or purple white pollen grain; but it will have tall purple, short purple, tall white, and short white seeds and pollen grains in equal numbers, and were these joined together by chance the conjunctions would result in nine purple tall, three purple short, three white tall, one white short—which are just the ratios we do find.

That, then, is Mendel's theory: he investigated merely the laws that govern heredity in plant hybrids, but his theory has thrown considerable light on hybridisation and hereditary transmission in the animal world.

Bateson, who has carried on Mendel's work and applied and developed his theory, declares, 'As a consequence of the application of Mendel's principles, that vast medley of seemingly capricious facts which have been recorded as to heredity and variation is rapidly being shaped into an orderly and consistent whole. A new world of intricate order, previously undreamt of, is disclosed. We are thus endowed with an instrument of peculiar range and precision, and we reach to certainty in problems of physiology which we might have supposed destined to continue for ages inscrutable.'

Again: 'The practical breeder of animals or plants, basing his methods on a determination of the Mendelian units and their properties, will, in many of his operations, be able to proceed with confidence

and rapidity. Lastly, those who as evolutionists and socialists are striving for wider views of the past or of the future for living things, may, by the use of Mendelian analysis, attain to a new and as yet limitless horizon.'

Bateson is, perhaps, a little too sanguine; but there can be no doubt that Mendelian principles offer a solution to many of the problems of human heredity. Already, a good many diseases and malformations have been shown to follow the laws of Mendelian inheritance and to behave as dominants, and the colour of the eye has also been shown to follow the same laws.

The question of the inheritance of sex naturally arises here. In fertilisation two different stocks of germ-plasm of somewhat different general potentialities conjoin, and, as we have seen, various determinants vie with each other for a place in the final composition of the animal. We can hardly doubt that the structural characters of sex are also determined by determinants.

Now, since the germ-plasm of the mother grew into a female, we may say that the ovum is probably feminine; and since the germ-plasm of the father grew into a male, we may say that the sperm of the father is probably masculine. Alterations in the sexual tendencies of ovum and sperm may, no doubt, be produced by the extrusion of chromosomes at maturation, but on the average the original tendency will be preserved. When, therefore, fertilisation occurs, masculine and feminine determinants compete, and the sex of the child will be determined by the successful competitor.

If this representation of the situation be correct,

it should be possible in some cases to 'spot' the likely winner by a consideration of the relative numbers of males and females in the families of the father and mother. If, for instance, the father's father have had only brothers, and the father's grandfather have had only brothers, and if the mother's mother had six sons and one daughter, there would seem to be every likelihood of male children.

We assume, of course, that determinants in any direction may be augmented or reduced in the process of fertilisation, so that a masculine or feminine tendency may be increased or diminished.

We ourselves have noted that when a very feminine woman is wedded to an effeminate man there is a tendency for the children to be daughters, and that when a masculine woman is married to a very virile man there is a tendency for the children to be sons; and the masculinity of a man and the femininity of a woman may, perhaps, be taken as rough criteria of the masculinity and femininity of their germ-plasms.

On this hypothesis it might be possible to influence the sex of the egg before, or even after, fertilisation by arranging diet and conditions so as to favour either lot of competing determinants. In lower organisms, such as bees, it is well known that sex can be altered by nutritional alterations, and it is not impossible that alterations might also be effected in the case of man and the higher animals.

The male animal burns faster than the female, that is perhaps the most important physiological distinction between the sexes; and it seems to

the writer that any measures that increase the oxygen in the blood might do something to give the germ-plasm or the egg a bias towards the masculine by favouring the determinants of male character.

It would be very interesting to give animals inhalations of oxygen before and during their breeding period, and to try the effect of oxygenated water on spawn of various kinds.

Since, too, the thymus gland seems to have some effect on the development, it would be interesting to see whether extract of thymus in the diet has any effect on sexual development.

So far, we have been supposing that the sex difference is a question of competition between male and female determinants in the fertilised ovum — determinants derived respectively from father and mother. But there are other ways of looking at the matter. We may regard the matter as a question of Mendelian combination.

It is possible, for instance, that the germ-plasm of the female contains both male and female determinants, and that the germ-plasm of the male contains only male determinants, and that the female is the dominant character. In that case, according to Mendelian principles of segregation of contrasted characters, the ova of the female would be half male and half female—or, to use the terminology we have been using, would half contain male determinants and half contain female determinants. On fertilisation, accordingly, half the ova would be male + male, *i.e.* male; and half male + female, *i.e.* female. There is a suggestion of this sex hybridism in the female, for in

certain cases a latent male seems to come out, and a woman develops a beard and a masculine voice and various masculine mental and temperamental characters. But, on the other hand, the theory is inconsistent with the fact that in some insects, *e.g.* in bees, unfertilised eggs are all male.

It is possible, again, on Mendelian principles, that the germ-plasm of the male is hybrid containing both male and female determinants, that the germ-plasm of the female is purely female, and that male is dominant to female. In this case, again, the conjunctions of fertilisation would produce equal numbers of males and females. But there are also difficulties in the way of the acceptance of this theory. In the first place, we do not find, in the human race at least, that female characters develop in males. In the second place, we find that unfertilised eggs are males, which could not be the case if the germ-plasm of the female was purely female.

Still a third hypothesis on Mendelian lines has been advanced. It has been suggested that both sexes are hybrid—that the male contains the female and the female contains the male. On Mendelian principles, then, there would be male and female sperm cells, and male and female ova, and they would form pure males, pure females, and hybrids; but this hypothesis assumes that the males and females do not conjoin with each other, so that only hybrids are formed, and further assumes that the sex of the hybrid depends on whether the sperm or the ovum be dominant. If the sperm be dominant, then, if a male sperm join a female ovum the result is a male, and if a female sperm join a male ovum the

result is a female, while if the ovum be dominant its contribution will decide the sex.

This theory does not seem quite satisfactory. It adopts the Mendelian procedure of segregating contrasted characters, but it rejects the Mendelian combinations and ratio which are the essence of the Mendelian theory, and it makes two assumptions simply to get out of difficulties.

It seems rather doubtful whether it is legitimate to consider primary sexual characters, male and female, as contrasted characters that behave as Mendelian units. The characters in both cases are rather blended characters than contrasted characters, and this is surely clearly demonstrated in the occurrence of hermaphroditism and similar monstrosities.

The most satisfactory explanation seems to be the explanation we first suggested: *i.e.* that the germ-plasm of the male and the germ-plasm of the female have each determinants of both male and female characters, but that the male determinants are stronger in the male germ-plasm, and the female determinants stronger in the female germ-plasm. Granted so much—and so much is surely proved by the male and female products of the respective germ-plasms—then it naturally follows that sex depends on the result of the competition of the male and female determinants in the fertilised egg—a result that may be possibly influenced by air, food, exercise, or drugs.

CHAPTER XVII

THE EVOLUTIONARY POSITION OF MAN

'Where wast thou when I laid the foundations of the earth? Declare if thou hast understanding. Who hast laid the measures thereof if thou knowest? Or who hath stretched the line upon it? Whereupon are the foundations thereof fastened, or who laid the corner-stone thereof, when the morning stars sang together, and all the sons of God shouted for joy?'

> 'Then the round earth grew furrowed and grew frore,
> And the encircling steam,
> Condensing in a stream,
> Hissed boiling, bubbling on a barren shore,
> Till the Word spake, and then
> There blossomed flowers, and beasts, and souls of men.'

Man is a product of a process of evolution that began in the fire-mist and is not yet finished. His flesh and bones were in the making when the earth was a spluttering orb of molten metal. In the first warm seas his blood was being compounded. Breath for his nostrils was being prepared when the first volcanoes belched their gases over a desolate world of scoriæ and lava. So astrophysics, and geology, and chemistry, and biology, and many other sciences tell us.

All the elements that go to the making of a man were at one time darting about as gaseous molecules, at the rate of many miles a minute. Before that

they perhaps existed for a time in a fragmentary, mysterious, half-dematerialised state as electrons. 'All our poetry,' said Tyndall, 'all our science, all our art—Plato, Shakespeare, Newton, and Raphael—are potential in the fires of the sun.'

So far all sciences and all scientists are agreed; and they are all agreed that all life came out of the inorganic. But just exactly how it emerged, or when it emerged, or in what shape it emerged, are more debatable matters.

Many think that life originated in the warm silt of circumpolar seas, since there, first, the temperature of the water would fall to a temperature compatible with the functions of life, and that the first living organisms were green cells capable of gaining substance and energy from the carbon-dioxide of the primitive atmosphere, or perhaps bacteria capable of growing in solutions of inorganic salts. From these primitive organisms, according to modern doctrines of evolution, more and more complicated organisms were gradually evolved, until finally man came into being.

This doctrine of organic evolution as opposed to the doctrine of special creation was established as the fundamental basis of biology by the work of Darwin and the teaching of Huxley and Tyndall. Before Darwin's time it had been taught in some form by Oken and Buffon, and Goethe, and Erasmus Darwin, and St Hilaire, and Treviranus, and Lamarck. Treviranus declared: 'In every living being there exists a capacity for endless diversity of form; each possesses the power of adapting its organisation to the variations of the external world, and it is this power, called into activity by cosmic

changes, which has enabled the simple zoophytes of the primitive world to climb to higher and higher stages of organisation, and has brought endless variety into nature.' Lamarck worked out the idea in detail, and showed how the inheritance of acquired characters would produce a progressive evolution. He also developed the very useful idea of a genealogical tree.

But not till 1859, when Darwin's *Origin of Species* appeared, did the doctrine of organic evolution get a real hold upon biological science.

Darwin for the first time suggested machinery which seemed competent to produce by known natural processes all the present multitudes of species. Up to the time of his historical book, evolution was admitted to have produced varieties within species, but most people considered the boundaries of species inviolate and inviolable.

Darwin's theory was founded on inference from masses of observed facts.

It was a known fact that every species tends to multiply and increase, that every member of the species tends to vary, to some slight extent at least, from its fellows, and to hand down its variations to its progeny. Darwin started with these facts, and pointed out that under natural conditions there is among all animals a struggle for existence and a struggle for opportunity to reproduce their kind. In this struggle any variations that increase the animal's chance of life, and chance of propagating its kind, would tend to be reproduced and perpetuated; while variations that handicapped the animal in its struggle to live and to reproduce offspring would tend to die out, since the animals thus handicapped

would be more liable to perish or to fail to propagate their kind.

Thus, by a selection and rejection of variations there would be a progressive modification in form and function, and an adaptation of each animal to the requirements of its environment. As Professor Kellogg puts it: 'The exquisite adaptation of the parts and functions of the animal and plant as we see it every day, to our infinite admiration and wonder, has all come to exist through the purely mechanical, inevitable weeding-out and selecting by Nature (by the environmental determining of what may and what may not live through uncounted generations in unreckonable time).'

Such a natural, simple explanation of the origin of species by the operation of factors within everyone's ken was very welcome to all scientific thinkers, and soon the whole theory of organic evolution was put on a Darwinian basis.

Carried to its logical conclusion, the Darwinian theory explains not only the origin of one species from another species, but the evolution of all organisms from some primitive simple organism; and from Darwin's time up till quite recent years such an evolutionary ascent from amœba to man has been the unwavering belief of science.

But now it begins to be perceived that the Darwinian machinery is not capable of accounting for all the meticulous and delicate adaptations of the multitudinous species of animals and plants—that, indeed, it is no more possible to explain a higher animal by an appeal to the action of environment on chance variations than it is possible to explain Shakespeare's plays, which are nothing more nor

less than the fruits of evolution, and must come under the explanation offered by such an hypothesis.

To say that an eye survived because it gave sight to its possessor, and, with the sight, a better chance of living, and a better chance of procreating and so of transmitting the precious possession, is to take a very superficial view of the matter. It is like saying that a key survives because it fits a keyhole and opens and unopens a lock, or that the piston of a motor-engine survives because it fits the cylinder.

It is perfectly true that a key, in a sense, survives because it fits a keyhole and unlocks a lock, and it is perfectly true that a piston, in a sense, survives because it fits a cylinder. But give a man a mountain of iron and let him make all sizes and shapes of objects he can think of, he will never make a key to fit and turn a lock unless he start with the idea of a key and keyhole, and he will never make a piston to fit a cylinder unless he start with the idea of piston and cylinder. The key may survive, the piston and the eye may survive because they fit, but the fact that the fitting produces such results—the unlocking of a door, or the motion of a motor-car, or the writing of a book,—shows that they were intended to fit and made to fit, and that the fitting was not a matter of chance variations that finally hit on a happy result. Moreover, to keep to the metaphor in the case of the eye, the key was made long before the making of certain keyholes in the door of life. The most important function of the eye of civilised man nowadays is to read, and the eye was made millions of years before

books were written. And in all the emergencies of structure there seems to be an anticipation of future uses.

No doubt environment does plane and polish by extirpating unfit variations and by selecting fit variations; but they are variations of a theme, of a plan, not chance variations.

All variations, moreover, are not adaptive: they emerge and they persist, even though they have no vital and no matrimonial value. And the variations that *are* adaptive are so multitudinous and so adapted to so many different circumstances, that it seems impossible they could be a selection from *chance* variations.

How does the right and the specific so often and so opportunely arise, when there are thousands of useless and even deadly variations possible, and when the right variation would often seem to require an extraordinary amount of foresight and ingenuity to discover it?

Admitting that the adaptive variations have been perpetuated by their survival-value, yet it is difficult to understand how they happened to become candidates at all, and how any processes of environment selection could have been at once so persistent, and consistent, and stringent, and yet so versatile and catholic as to select so many variations, having survival-value in so many different ways, and requiring such very different concatenations of circumstances to favour their selection. Thus the ear might happen upon a very useful variation; but what survival-value would it have against the silent attack of a tubercle bacillus. Or the eye might have happened upon a great improvement, but what

survival-value would it have in the case of a small-pox epidemic. Different variations, however great improvements they may be, must vary in their survival-value, and out-value each other, in turn, according to time and place and accidental circumstances.

'Granted,' as the writer has said elsewhere, 'that the rudimentary eye varies in certain directions, and that certain variations, however slight, might be more useful than others, is it conceivable that their usefulness should invariably have life and death value, so that individuals should be selected solely by eyesight, for centuries and generations sufficient to produce man's finished eye?

'How do we find men selected nowadays? One by his bank account, one by his biceps, one by his club foot, one by his resistance to infantile enteritis, one by his piety, one by his impiety, and so on. How, then, can any one variation be progressively improved by selection when selection is so capricious in its criteria? Infantile enteritis alone would put an end to selection that might be proceeding satisfactorily on fifty different lines. It is almost impossible to believe that any one organ or character can have survival-value long enough, and often enough, to endure its own elaboration and perpetuation in a complicated and varying environment, selecting now this, now that.

'The fact seems to be that, on the whole, selection is very much a matter of chance, and proceeds on very erratic and inconsistent lines. The pig or the squirrel that eliminates the acorn, the germ or railway accident that eliminates the man, are not at all likely to make for progress in any specific

direction by the consistent selection. When one considers the multitude of eliminating agents, each destroying on different principles and on capricious principles, the survival-value of any slight fluctuating variation in the hands of selection seems very dubitable.'

It must be remembered, too, that variations occur, as a rule, in only one or two cases: they are, apart from *mutations*—a matter we shall soon consider—certain to be watered down by marriage, or to fail to survive in a contest where quantity often is more than quality. A little extra luck, a little extra fertility, will often suffice to more than counterbalance a favourable variation.

It is true that breeders often succeed in producing new breeds; but they do so by isolation and by constantly selecting, as natural conditions seldom do select, the characters they wish to preserve and to emphasise. Were the breeds produced by breeders allowed to breed promiscuously, the result would be a reversion to ancestral type.

Nor can Darwinism longer invoke the doctrine of inheritance of acquired characters—a doctrine on which Darwin, Huxley, and Spencer all built the theory of Darwinian evolution.

We cannot deny that environment does select and reject, and that considerable changes may be effected by such means; but it is as absurd to say that all the adaptations of natural species, and all the structures and functions of natural species, are the result of environment acting on casual variations in an amœba, as to say that the words on this paper are the result of casual variations

acting on a drop of ink. There are definite prescience, definite provision against contingencies in the adaptations of living organisms, and definite intricate correlations between the adaptations, that could never be the result of natural environment selecting variations fluctuating round a mean. When I write, I add and reject certain words and finally I use blotting-paper, and natural selection has about as much to do with the creation of animals and plants as blotting-paper has to do with the writing on this page. The more, indeed, we study the functions and structures of animals, the more certain we grow that there is and was a mind at work definitely moulding and moving them to a certain goal—a mind acting with absolute precision, knowing from the first exactly what it intended to bring about—arranging in the fire-mist that the world should have water on its surface and an atmosphere of oxygen and nitrogen, arranging that organisms should have gills and lungs to breathe oxygen, and that the breathing of the oxygen should produce certain results. It is not held that these consummations were the result of the selection of casual variations, and all the results that grew out of these beginnings were pre-ordained and foreseen and directed.

Some of the most extraordinary adaptive functions of living organisms cannot be explained by any theory of casual variation and selection.

Take the case of that mass of adaptations—the whale. Its ancestors, according to Darwinian theory, had four legs and lived on land: they had also hairy skins and no tail-fins. The whale has its fore-legs transformed into flippers; its hind-

legs are reduced to vestiges, and it has only a few hairs left on its skin. The muscles of its ears have disappeared; its teeth are rudimentary; its nostrils are in its forehead; it has an enormous mouth cavity. It has also great masses of blubber under its skin; it is shaped like a fish, and it has a powerful tail-fin.

Is it possible to believe that all these adaptations were the result of chance variations? How did they happen to arise in the right animal at the right time? How were they preserved in their beginnings before they could have had any life and death value to the animal? How did so many structures vary at all in the right direction.

Or take the case of the caterpillar of the butterfly. At a certain stage in its career 'all the internal organs which have so far enabled it to live and grow—in fact, the whole body it has built up, with the exception of a few microscopic groups of cells—become rapidly decomposed into its physiological elements, a structureless, creamy, but still living protoplasm; and when this is completed, usually in a few days, there begins at once the building up of a new, a perfectly different, and a much more highly organised creature, both externally and internally—a creature comparable in organisation with the bird itself.'

By what possible process of selection of variations can such phenomena be explained. The caterpillar's own white blood corpuscles dissolve the whole of the caterpillar's internal organs—muscles, intestines, nerves, respiratory tubules,—and leave only a few cells which feed on the

debris of the caterpillar and grow into a beautiful butterfly, wings and all.

Did the white blood-cells begin by devouring a few muscles and no more? Did they by mistake devour the butterfly cells, and make casual experiments in all directions till, finally, they by chance devoured the whole body except the butterfly cells, and lo—a butterfly? And if they did, how did the white blood-cells of the next caterpillars know the dodge and proceed to carry it out. If variations in such a complicated affair happened to go right once, they were just as likely, in fact, far more likely, to go wrong another time.

The idea that such processes and such results are produced by selection of casual variations is quite preposterous.

Take the case of the bones—another case of cell accomplishment. They are built, as we have seen, by little cells known as *osteoblasts* and *osteoclasts.* These lay the lime in exactly the right way to give the bone strength and lightness. They are in the hands of a chain of cause and effect that reaches back to the fire-mist. The lime was ready for them: they are actuated in such a way as to do the right thing at the right time. It is not a case of certain cells or groups of cells having been selected because they did useful things. Even supposing, as is very doubtful, that strength of bone would be selected, there can have been no selection in this case. The cells work together in co-operation: the work of the millions and millions of them is co-ordinated to one end, the value of the work of each depends on the work of all, the value of the work of all depends on the

work of each. Let the bone be injured, let millions of the cells be destroyed, new millions will come from the membrane of the bone, and will, in conjunction with the others, repair the injured bone. It matters not what bone is injured: it may be a bone in an animal which is not broken once in a thousand years, yet these cells are ready and do the work perfectly. And, mark this, cells are ready to do the work that is not their usual work, are ready to do work that they have never done before.

This inexplicable versatility of cells is seen in many other cases. If the lens of the eye of the *Salamandra maculata* be removed and the iris left, the regeneration of the lens takes place at the upper part of the iris, and if this upper part of the iris itself be taken away, the regeneration takes place in the inner or retinal layer of the remaining region. Thus, parts differently situated, differently constituted, meant normally for different functions, are capable of performing the same duties, and even of manufacturing, when necessary, the same pieces of the machine.

Again take the formation of antitoxins. Whatever bacterial poison be put into the blood, the cells react and throw into the blood just exactly the right chemical substances to neutralise them. Introduce into a community a disease from which it has never suffered before, and yet the cellular chemists are able to produce exactly the right substances to fight it. It is true that the cellular chemists may not be so competent as the cellular chemists of a community accustomed to the disease, and it is true that Darwinism may account for this increased competency. The point remains

that cells which could not possibly have been selected by the disease are yet ready to produce subtle antitoxic chemical substances.

Such examples might be multiplied almost indefinitely: the instincts of insects alone might supply dozens of illustrations. But even the few examples we have cited should suffice to show that Nature does not blunder on to her goal, but knows exactly where she is going, and always has known.

In addition, however, it may be pointed out that research, since Darwin's time, has shown that the most careful and stringent selection cannot cultivate a variation beyond a certain point. By a careful selection of sugar-beets the average percentage of sugar in the beet can be about doubled. But that is the greatest increase that can be produced, and the percentage tends to fall at once if selection ceases. De Vries—a great authority on matters of heredity, whose special work we shall soon discuss—declares that 'we may lay it down as a general rule, that a doubling or halving of the original mean is about the most that can be attained by selection'; and that 'continued selection by no means fixes the character chosen, but by separating the race further from the type from which it sprang, continually adds to the risk of regression.'

The variations that we see in most plants and animals are largely nutritional in character; and are not transmitted. Even those variations which are germinal, and which are transmitted, cannot be augmented by selective breeding beyond a certain point.

CHAPTER XVIII

THE EVOLUTIONARY POSITION OF MAN—*Continued*

> 'And yet the Soul in Whom all beings are,
> Discerns so deep, foresees so far,
> He plans the beauty of a star
> Before the stellar mist is made
> And in the fire
> He moulds to his desire
> The tiny blossom and the tender blade.'

> 'Every star is needful for a rose.'

Seeing that small variations tend to fluctuate, and cannot be much enlarged by cultivation, some modern scientists have been inclined to think that evolution has proceeded not by small variations, but by larger variations, which have been called *mutations.* These larger variations are distinguished not only by their size, but by their transmissibility. They are transmitted to offspring, and are transmitted, too, after the manner of Mendelian units.

Both Huxley and Galton had an idea that Nature sometimes proceeded by larger steps. Huxley, indeed, remarked in an review of the 'Origin of Species': 'Mr Darwin's position might, we think, have been even stronger than it is, if he had not embarrassed himself with the aphorism, "*Natura non fecit saltum,*" which turns up so often in his pages. We believe . . . that Nature does make

jumps now and then, and a recognition of the fact is of no small importance in disposing of many minor objections to the doctrine of transmutation.'

But it was De Vries, the Dutch botanist, who first made a thorough scientific study of mutations. He was led to this study by the discovery of a species of evening primrose which was in the very act of mutating. He planted nine plants in the botanical garden in Amsterdam, and sowed their seeds. From the seed were produced in seven generations 50,000 plants, and of these 800 were mutants. He classified the 800 mutants in seven new species, and after a thorough study of them, formulated the following laws of mutation: (1) New elementary species arise suddenly without transitional forms; (2) New elementary species are, as a rule, absolutely constant from the moment they arise; (3) New elementary species appear in large numbers at the same time, or, at any rate, during the same period; (4) The mutations to which the origin of new elementary species is due, appears to be indefinite; that is to say, the changes may affect all organs, and seem to take place in almost every conceivable direction; (5) Mutability appears periodically.

In the animal world there are some notable instances of mutations that have given rise to new species. There are, for instance, the Ancon sheep, bred from a ram lamb born in 1791, with short, crooked legs and a long back like a turnspit dog; and the Mauchamp sheep, bred from a merino ram lamb, with remarkable long, smooth, straight and silky wool. The hornless Paraguay cattle and the polled Herefords are also well-known mutations.

Not all mutations, however, are so marked and gross, and it has lately been shown that the plants of any species contain numerous mutants, varying very little from the mean.

An attempt, then, has been made to base evolution upon mutants. The advantage of this basis is that mutants, as defined, do not fluctuate, and that they may represent big leaps in structure and function—leaps that the ordinary fluctuating variations are incapable of achieving. When mutations, moreover, cross with the parental unmutated species, they are not neutralised, but appear in Mendelian ratio to take their part in the struggle for existence.

It seems very likely that many species have been formed in this way; but we must assume, that if so, Nature looked before she leaped and knew where she was going, for the majority of characters that mark and distinguish species are nearly all characters which are advantageous to them in the special circumstances under which they are placed, or are likely to be placed. It is as impossible to believe that the evolution of a man from an amœba, or a fish, or a monkey—if such evolution did take place—was a matter of *casual* mutations, as of *casual* variations. Whether the variations were large or small, there is every reason to believe that they were so directed as to be on the path of progress. The numbers of lucky hits that must have been made all the way along far exceed the possibilities of happy chances. The number of lucky hits that go to the making of a man are almost infinite; the correlated complexes of structure and function are innumerable, and if there had been half as many

unlucky hits as lucky hits, a man could never have been made: he would have died out long ago.

Darwinism was a scientific triumph—a triumph of an honest, patient, courageous mind seeking for truth: it was a scientific triumph, and yet it was a spiritual disaster; for it deprived life of a great part of its mystery, and substituted the hand of Chance for the Hand of an omniscient Creator, and the world ought to rejoice that the progress of science has now left Darwinism behind it.

Species may be occasionally developed from other species by environmental selection of variations; but the organism and its variations are fitted to its environment, and fitted also to various contingencies by a Power that presciently prepared and produced both the environment, the organism, and the variations. Nature leaps, and she looks before she leaps. She does not make a thousand random attempts that environment may preserve a lucky success, and if she blunders she blunders straight to the goal.

For forty or fifty years organic evolution has taken its stand on the Darwinian hypothesis. The machinery of evolution suggested by Darwin seemed adequate and potent: no one doubted that, given a piece of primitive protoplasm, and an environment, and enough casual variations, then amœba, and whales, and midges, and butterflies, and humming-birds, and monkeys, and men would inevitably emerge in time. So seductive, so welcome was his more or less mechanical scheme, that there seemed nothing very miraculous about such an emergence. If a wolf could grow

into a toy pom or a mastiff, why should not a marmoset grow into a man? The mind felt less amazement at the co-ordinations and adaptations of living organisms if it could conceive them as the automatic result of infinite time and infinitesimal casual variations. Given sufficient time, and sufficient variation, biology imagined that, like Laplace, it could say of Deity, 'Sire, Je n'ai pas besoin de cette hypothèse.'

But, as we have said, a deeper study of the facts of physiology and heredity has overthrown Darwinism, and now the question arises — Can evolution be maintained without the machinery he provided for the process. It was adumbrated but not really accepted before his time, and now that his time is over, must it, too, go?

Even apart from Darwinism, even apart from his doctrine of casual variation and selection, there is a great deal of evidence in favour of evolution, organic and inorganic. The spectroscope shows us that atoms are derived from electrons; chemistry reveals that all matter, organic and inorganic, is composed of atoms; comparative anatomy and physiology declare that all animals and all plants can be arranged in an ascending series, with only small gaps between the species; embryology discovers a recapitulation of phylogeny in embryogeny; palæontology informs us that species succeeded to species in the history of the world; genetics proves to us that in some cases at least species have actually originated by mutations.

Such evidence is fairly strong but it is not conclusive, and it loses much of its force when deprived of the support of the Darwinian theory.

But further, the moment we surrender the pseudo-automatic machinery of Darwin; the moment we admit the possibility of prescient mutations; the moment we admit that living organisms are creations of Mind—that same moment the whole logical situation changes. If the Darwinian machinery were competent to make a man out of an amœba, then in view of the evidence of ascending species it was quite easy to believe that the amœba was in time actually developed into a man; but when we take away the pseudo-automatic machinery that accounted for the transformation and replace it by the intervention of a prescient mind, there is no advantage at all in the evolutionary hypothesis. The evolutionary hypothesis was an endeavour to evade special creation, and to dispense with a Creative Mind; and if now we have to call in Providence to explain the character of the mutations that lead to the evolutionary ascent, we might just as well call in Providence to explain the species. We may say either that a prescient mind added a speech centre to the third left frontal convolution of a monkey, and thus by a miraculous mutation made the monkey into a man, or we may say that a prescient mind made a man without any such process of piecemeal miracles.

There is no proof at all—there never was a proof at all that all species originated from one primitive species: the hypothesis was only advanced and accepted because on the Darwinian hypothesis one species was all that seemed necessary, and because a single simple beginning of life seemed to rid Nature of the Supernatural. But the Supernatural has come back again: it has been found that only

the Supernatural will suffice to account for the achievement of the Supernatural, and it would be just as easy for the Supernatural to make fifty primitive species as one.

As Science stands at present, we are at liberty to believe either that life began as some unicellular primitive organism which was constituted in such a way that part of its progeny remain to this day as unicellular organisms—yeast cells, microbes, and so on—and that part of its progeny became in time jelly-fish, and star-fish, and whales, and midges, and lizards, and larks, and monkeys, and men. A very extraordinary primitive organism that must have been, with half a million species potentially in its loins!

Such a theory is quite possible: palæontology proves that primitive organisms came first, and comparative anatomy shows us that many divergent forms are really built upon the same scheme and have the same structures, adapted to different conditions. But to the writer it seems much more likely, for many reasons, that life began in many shapes and forms, and that there was a multitudinous primeval parturition of the inorganic; so that the species at present known sprang from many different organic beginnings.

It is usually assumed that organic matter with the functions known as vital came into being as a chemical complex when the earth had cooled to a certain point, and that it would be quite possible for exactly the same chemical complexes with the same vital functions to be formed now from the cool inorganic constituents of the earth's crust; and one eminent scientist, Bastian, claims that he

has seen low forms of life come into being in inorganic solutions. To the writer it seems very unlikely that the energies of life began in the cooling crust, and that in the cooling crust they may begin again. From nebula to a world teeming with life, the earth has evolved step by step; but every step and every stage has been directed, and conditioned, and caused by the energy with which it started. The water in the ocean-beds, the lava flowing from volcanoes, the oxygen molecules darting and colliding in the atmosphere, all are as they are, and where they are, because of the composition and energy of the original nebula. There has been transformation of energy, there has been rearrangement of molecules, but nothing has come out of the nebula that was not in it from the first. At one time the world was at a temperature of 6000° Fahrenheit or thereabout, and now its crust is cool; but the heat has not been merely radiated into space; a great part of it has been changed into energy of position (such energy of position as is seen in the clouds) and into chemical energy, and, the writer believes, also into that special form of energy known as *vital energy*, which is manifested in assimilation, reproduction, molar motion, thought.

There seems a good deal to be said for Professor Pflüger's theory that the chemical compound *cyanogen* was the nucleus of living matter. Cyanogen is formed, not at the temperature of the earth's cool crust, but at incandescent heat. 'Accordingly, nothing is clearer than the possibility of the formation of cyanogen compounds when the earth was wholly or partially in a fiery or heated state.

now we consider the immeasurably long time during which the cooling of the earth's surface dragged slowly along, cyanogen and hydrocarbon substances had time and opportunity to indulge extensively their great tendency towards transformation . . . and to pass over, with the aid of oxygen, and, later, of water and salts, into that self-destructive proteid, living matter. . . . The first proteid to arise was living matter, endowed in all its radicles with the property of vigorously attracting similar constituents, adding them chemically to its molecule, and thus growing *ad infinitum.*' ('History of European Thought in the Nineteenth Century.')

The property of vigorously attracting similar constituents, adding them chemically to its molecule was, no doubt, a power derived by transformation of thermal into chemical energy (we see a similar transformation in the formation of starch in the formation of a plant), and it is surely almost necessary to believe that the tremendous and specific energies of life required the tremendous thermal energy of the molten world to generate them. That tremendous thermal energy was certainly behind them, and must in some way have been in causal connection with them. *Ex nihilo nihil fit,* and out of the cool crust of the world life never arose, and is never likely to rise. Man can come into existence as a living organism only when God breathes into his nostrils the breath of life; and the breath of life is fire.

We assert, then, that life probably began as chemical nuclei, which were dowered with great potential energy, and exercised it in the form of chemical affinity, producing compounds still

energetic and manifesting energy in the forms of chemical affinity, heat, and mechanical power. We see the same process and principle still at work in the *growth* of living organisms: it all starts round a nucleus of carbon energised by the sun.

Now in what shape or form did the first living things appear? The orthodox scientific answer is that it arose from the cooled crust of the earth as a sort of living slime, and Huxley at one time thought he had found such slime in the depths of the ocean. The orthodox religious view is that God spake

> 'The earth obeyed, and straight
> Op'ning her fertile womb, teemed at a birth
> Innumerous living creatures, perfect forms
> Limbed and full grown. Out of the ground uprose,
> As from his lair, the wild beast, where he wons
> In forest wild, in thicket, brake, or den:
> Among the trees they rose, they rose and walked;
> The cattle in the fields and meadows green:
> Those rare and solitary, these in flocks
> Pasturing at once, and in broad herds upsprung.
> The grassy clods now calved, now half appeared
> The tawny lion, pawing to get free
> His hinder parts, then springs as broken from bonds,
> And rampant shakes his brindled mane.'

One can hardly accept the Miltonic account; but on the other hand there seems no necessity to accept the scientific slime theory. It is certain that lions and cattle and men did not arise limbed and full grown; but there is no necessity to bring them from the slime *via* amœba and sea-anemones. We find that in the womb the ovum grows to a baby in a few months' time, and we can surely imagine that at the dawn of life some

primordial germplasm, even without a womb, grew into monstrous organisms with male and female characters capable of bearing at once the higher sexual animals.

We escape no difficulty whatsoever by spreading the making of a man over millions and millions of years, and by assuming a slime capable of transition through lower into higher organisms. It is only a hypothesis accepted by man's mind because time and transition forms (especially if we also assume casual variations and blunders) makes the creation seem less marvellous; but really the emergence of the urancestors of a lion from magic miocene mud were no whit more marvellous and miraculous than its present origin from a microscopic ovum. The growth of an animal seed in the mud is *a priori* quite as likely as the growth of a vegetable seed in the mud; and the structure and function of an amœba is little less complicated and wonderful than the structure and function of a larger animal. Size is not the criterion of complexity. A liver cell has been calculated to contain 300,000,000,000,000 atoms in 64,000,000,000 molecules, and has been compared in its mechanical and functional complexity to a 'Mauretania' full of chronometers, and the shell of a diatom is as wonderful as the skeleton, it is 'of extraordinary complexity and most singular beauty.' Again the work done by a proliferating bacterium is quite comparable to the work done by a charging rhinoceros.

E. B. Wilson, who has made a special study of the cell, says that the study 'has on the whole seemed to widen rather than to narrow the

enormous gap that separates even the lowest forms of life from the inorganic world.'

We suggest, therefore, that the nuclei of life began when the world was still hot, that the nuclei were various in character and possessed of sufficient energy to build up germplasms of various kinds. It is *a priori* more likely that many kinds of vital nuclei were formed than that one only was produced. It is more likely that midges and lions were produced from separate beginnings than from the same primordium, and it is even more likely, we believe, that man and monkeys had separate origin in the fire-mist, than that they sprang from the same primordial germplasm.

The mere fact that organisms can be arranged in an arborescent form according to their likeness is no proof at all of genetic continuity—no more proof than the likeness between the eye of a pecten and the eye of a man is proof of genetic connection. There are about half a million species of animals, and between such numbers likenesses must occur quite apart from genetic relation. Nor does the fact that animals exhibit in the embryogeny features and characters of other lower animals prove genetic derivation from these animals, 'for development may be considered the dynamical result of protoplasmic chemistry, and if that be so, we should expect a similarity of developmental processes in all species derived from protoplasmic ova even if not genetically related to it.'

As Bergson puts it:—'Roads may fork or byeways may be opened along which dissociated elements may evolve in an independent manner, but, nevertheless, it is in virtue of the primitive

impetus of the whole that the movement of the parts continues. Something of the whole, therefore, must abide in the parts; and this common element will be evident to us in some way, perhaps by the presence of identical organs in very different organisms.'

The sequence in time, too, that we find in the palæontological records does not prove genetic connection; it merely shows that what we consider the lower and simpler organisms preceded in time the organisms we consider higher and more complex; but this might well happen without genetic connection.

Much stress is often laid on vestigial structures as proof of genetic relationship; thus the membrana nictitans, or third eyelid of the eye, is found in a very ill-developed condition in the eye of a man, and is thought to show descent from shark-like fishes, since in sharks the membrane is well developed. But such reasoning is surely rather rash and superficial.

Even vestigial structures that seemed at one time proofs positive of genealogical relationship are found in the light of recent research to be very inconclusive proofs indeed.

The muscle called the *plantaris longus* which occurs in a vestigial condition in man, seemed a very evident proof of man's blood relations to the anthropoid. Professor Arthur Keith, in his excellent little book on the human body, states the case well, and since it is about the strongest evidence of relationship that vestiges can offer, we may take it as a test case. This is Professor Arthur Keith's statement of the matter:

'Beneath the calf of the leg there is an exact counterpart of the palmaris longus. This muscle—the plantaris longus—is also vestigial; it is often little more than a white tendinous cord, having no muscular belly; in five per cent. of men it is altogether absent. The anthropoids are similar to man in this respect. In the gorilla it has almost disappeared. In all pronograde apes it is well developed, and instead of ending on the heel as in man, passes into the sole of the foot, where its tendon spreads out to form a stout membrane (the plantar fascia) under the skin of the sole.

'As a monkey runs along on all fours, its heel will be observed to be turned upwards off the ground; there is a supple joint — the mid-tarsal joint—just in front of the ankle, which allows the hinder part of the foot to be bent easily upwards. A change in posture, such as is seen in anthropoids, is accompanied by a stiffening of the mid-tarsal joint; the tarsal part of the foot is enlarged to provide a more firm support for the weight of the anthropoid's upright body. The heel is prolonged backwards, and the heel is not bent upwards as in monkeys, but the whole sole is applied flatly to the branch as the anthropoid passes along it in an erect or semi-erect posture. When the heel is thus applied to the ground in consequence of the orthograde posture, it presses against the tendon of the plantaris; indeed, the heel grows through the tendon, thus cutting off the muscular part of the leg from the tendinous part in the foot. This condition is seen in the legs of man and of the anthropoids, and is proof that all of them have passed through a pronograde stage.'

Where is the proof? Professor Arthur Keith will not, of course, maintain that the condition found in man is the result of the selection of casual variations. If the change occurred at all in the course of the evolution of an anthropoid, it must have occurred as a mutation, since any slight variation in that direction would be a disadvantage, and even if an advantage, could not be subject to stringent selection. If it occurred at all, then in the course of the evolution of a race it must have occurred as a mutation. But it is no more likely to have occurred as a mutation in an anthropoid, than as an original feature in a species, the species *Homo sapiens*.

Likenesses, so-called vestigial remains, cannot be taken to prove genealogical relationship, unless it be a relation as far removed as the incandescent elements that formed the first nuclei of living things. With regard, indeed, to most vestigial remains so called, we have no proof at all that they are vestigial remains. We have no proof that the whale ever had a hairy coat, or that it ever had functional hind legs, and it seems to the writer that the hairs and the rudimentary limbs are no proof at all of a descent from hairy, walking animals, but much more likely proof that the germplasm of whales and the germplasm of four-footed animals have chemical elements in common, and tend to evolve on the same lines, even as practically all protoplasm tends to develop *in symmetrical* fashion.

So far as logic and as science go, we have as much right to believe in numerous beginnings of life, and at beginnings at a high point of structure

and function, as to believe in the beginning of all things in a common slime at a low point of structure and function—we have quite as much right to believe, notwithstanding vestigial tails, that men and monkeys arose from separate beginnings as that they are descended from common ancestors. And we have far more reason to believe that the world and all that therein is was created by a prescient Intelligence than that it is the outcome of the selection of environment on casual variations.

CHAPTER XIX

DISEASE, OLD AGE, DEATH

> 'How can a single drop
> Of liquid potent poison drown the soul
> Which holds the suns and stars and hills and seas
> And hope and love, yea, and the poison-drop
> Within its various vast infinitude?
> Can a soul grow a body in a womb
> With eyes, and ears, with hand, and heart and brain?—
> Can a seed build merely of earth and air
> A rose with inspiration for a soul,
> Without persuading us that life and death
> Are mysteries so deep, we dare not say
> This rose is withered, so its charm is gone,
> This heart is still, therefore the soul is dead?'

Wonderful though the human body be, it is not invulnerable, and it is not immortal: it is a prey to many diseases: it is withered by old age; it is crumbled into dust by the cold, bony fingers of death.

Some diseases man brings with him from his ancestral germplasm; some he contracts from his parents' bodies; some attack him from various quarters on his journey through life. Strange, and weird, and terrible many of the diseases are! He may be born with his infant head full of water, bulging like a balloon; the sins of his fathers may be visited upon him, and he may be born wizened and grey and senile, or deaf

and dumb; he may get infantile paralysis, and some of his limbs may cease to grow; he may suffer from the diseases called St Vitus Dance, or epilepsy, and his muscles will twitch and jerk without the sanction of his volition; he may get leprosy, and find his flesh rot off him, or he may get sleeping-sickness, and sleep, and sleep, till the sleep of death comes; or he may have thyroid disease, and grow heavy, and gross, and dull, and stupid; or he may become insane and imagine himself Joan of Arc or Julius Cæsar; or he may get pernicious anæmia, and find his red blood cells melting away; or he may get leukæmia, and find his white blood cells overcrowding in his blood; or he may have lips and nose eaten away by lupus, or cancer may attack and mutilate him, or rheumatoid arthritis may stiffen and distort his joints, or he may be subject to the disease hæmophilia, and bleed to death from a trifling cut; or elephantiasis may give him limbs like an elephant, or leontiasis may give him the facial aspect of a lion. There is, indeed, no end to the diseases that dog him from the cradle to the grave, and if he escape them all, or most of them, there is always the inevitable unconquerable disease of old age to be faced.

The most lamentable of all diseases are, perhaps, the microbic diseases. Here is man, lord of the world, paragon of animals, rejoicing in his strength, glorying in his inheritance of beauty and wisdom! He inhales a few little microscopic cells, and in a short time his breath is panting, his heart is labouring, his mind is wandering, and death is waiting at his elbow. No courage, no wisdom,

no strength, avail to fight the invisible foes if once they invade the body in sufficient numbers. Is it any wonder that when men first began to imagine that such foes might be, they sometimes pictured them thus: 'The infecting particles that are immediately the pestilential matters' officers of execution are made of Nature's noblest materials, fire and blood, a composition truly military; and, as we may infer from their quality as well as activity, must be of the most beautiful form and gaudy and glorious colours, a flying army of the richest dress and finest livery, and one may think that the symptom of the plague of seeing beautiful and glorious colours took notice of by Mr Boyle was not merely fantastical apparition.'

We know all about microbes now. We grow them in soups and on potatoes. We stain them crimson and blue with coal-tar dyes. We find poisons to poison them; we find ways of helping our blood cells and tissue cells to conquer them; but they still remain slim and formidable foes. We are finding out ways to evade many of them; but our actual victories over them have been comparatively few.

We have found ways of evading and conquering the unknown microbe of small-pox: we have found ways both of evading and conquering the parasite that causes malaria: we have found ways of evading and conquering the spirochæta pallida—the microbe of the Hidden Plague: we have found ways of evading, if not of conquering, the microbe of Mediterranean or Malta Fever: we have found an antidote to the poison of the bacillus of diphtheria; but still the incidence rate and the death-rate from

most of these diseases are large, and we depend more on prevention than cure.

The most destructive microbic disease of the civilised world is probably tuberculosis. Its microbe, the *bacillus tuberculosis,* was discovered by Koch more than forty years ago; but though its death-rate has fallen, it still slays over 50,000 people annually in Great Britain. Our best weapons, so far, for fighting it are cleanliness, pure milk, fresh air, and good food; but some day some means may be found of killing them in the lungs and tissues. Meantime, the death-rate due to this disease is falling.

The next most destructive disease is perhaps malaria. Only towards the end of last century was the microbe discovered that caused the disease. Sir Ronald Ross, then Major Ronald Ross, discovered it in the intestines and salivary glands of a species of mosquito, and proved that the disease is inoculated by the bite of the mosquito. This was a remarkable discovery, for it showed the disease might be prevented by slaying mosquitoes, which are much more get-at-able than microbes. Our plan of campaign against this disease is very efficient, for we can destroy the mosquitoes and their larva; we can prevent the access of mosquitoes by mosquito-netting, and we can actually kill the microbes in the blood by means of quinine. By such measures malaria will be eventually exterminated. In Cuba, and at the Isthmus of Panama, where it was formerly deadly, it is now almost unknown. In the same way, the microbe of yellow fever was tracked to the proboscis of another species of mosquito, with the result that

precautions against the go-between mosquito has almost stamped out yellow fever in places where it used to be prevalent.

Successful campaigns against malaria and yellow fever, and hydrophobia, and diphtheria, and small-pox have certainly been great triumphs for science; and even greater was the triumph for science when Lister, by means of aseptic and anti-septic measures, discovered a way of curbing and usually conquering the virulent microbes of suppuration, and when the Austrian physician, Ignatius Philippus Semmelweiss, applied Listerian principles to the treatment of puerperal fever. In both cases hundreds of thousands of lives have been saved.

But science is not always victorious: many microbes still maim and murder as they will. Even within the last few years hundreds of thousands have died of sleeping sickness and the plague, and the tubercle bacillus, though closely watched, still succeeds in slaying its thousands.

Quite lately the Russian scientist, Metchnikoff, has maintained that old age itself is the result largely of poisons formed by microbes in the large intestine. The large intestine is certainly swarming with microbes, hundreds of billions, and though most of them are dead, yet some are living, and some certainly form poisons, such as *indol,* which are injurious to the tissues.

Metchnikoff's theory of the nature of many of the symptoms of old age is very interesting. He holds that most of the symptoms are due to poisoning or intoxication of connective tissue cells and phagocytes, which, when poisoned, do many things they ought not to do.

For instance, in old age the hair becomes white, and the reason for this, he explains, is that white cells like phagocytes, which he has named chromophages, devour and remove the pigment of the hair. The bones in old age become lighter and more brittle, and the reason of this is that cells in the bone become intoxicated and forget themselves so far as to gnaw at the bone and remove its lime salts. Again, the arteries in old age lose their elasticity and become thickened, owing to a formation of fibrous tissue and a deposition of lime salts. The connective tissues is formed, says Metchnikoff, by the anti-social activity of intoxicated connective tissue cells in the walls of the arteries; and the lime deposited in the arteries is the lime removed from the bones of the other perverse cells we have just mentioned.

Yet, again, in old age, the brain and nervous system lose vigour, and according to Metchnikoff, the reason of this deterioration is that wandering cells in the brain and nervous tissues become also intoxicated, and proceed to devour the nerve cells of the brain and spinal cord.

Now the question comes to be: If that be the nature of the symptoms of old age, might old age not be prevented or at least postponed by taking measures to combat the pernicious microbes. Metchnikoff is hopeful, and he has suggested various ways of fighting the foes.

In the first place, he suggests that the nobler tissues—the nerve cells, and muscle cells, and so on—might be strengthened to resist the poisons by injecting extracts of their own substance. The principle and merits of such measures we need

not now discuss, since Metchnikoff, himself, considers that they are not at present practicable.

In the second place, he suggests that the large intestine, which is a hot bed of the dangerous microbes, should be extirpated. That would be quite a possible surgical procedure, but in our present state of knowledge it is not likely that any one would submit to such a drastic operation, even on the chance of postponing old age.

In the third place, Metchnikoff has suggested that we should set a thief to catch a thief—that we should introduce into the intestine harmless microbes able and willing to devour the evil microbes, and he has recommended for the purpose the lactic acid bacillus (the bacillus that turns milk sour) since it has been found that lactic acid has an action antagonistic to the intestinal microbes. This is the measure upon which Metchnikoff chiefly relies, and he has used it, in his own case, to try to postpone old age. He is satisfied, too, that in his own case it has been successful for, though he comes of short-lived stock, he is now a man of seventy years of age and still fit for hard mental work.[1]

It may be pointed out that alcohol probably acts in the same way as intestinal toxins, and hastens the advent of old age.

No doubt there is a good deal of truth in Metchnikoff's theory; but it is probable that he rather exaggerates the importance of intestinal toxins as an ageing factor. It is quite possible that the misbehaviour of the cells is due to old age as much as to intoxication; for it seems as

[1] Since these lines were written Metchnikoff has died.

if the tissues of the body are endowed with only a certain amount of energy, and act both less correctly and efficiently as that energy diminishes. The energy imparted to germplasm by the thermal energy of the fire-mist, and to the body by the germplasm and the food cannot be infinite, and must in time run down.

Longevity seems to be a matter of stock and of innate constitution rather than of any rules of health. Sometimes healthy, healthy-living men, in whom there is no reason to suspect an undue amount of intestinal toxicity, become soon senile, while unhealthy men, who break all the rules of health, sometimes live to a great old age.

Perhaps the day will come when we will all live to the age of a hundred, and, like Kelvin, and Alfred Russel Wallace and Strathcona, preserve youth of intellect to the end, but sooner or later old age must come: it can never be entirely abolished.

Sooner or later the faculties must weaken; sooner or later senility must supervene. The chief consolation, perhaps, is to be found in the fact that even in death from old age the mental faculties, if well cultivated and well developed, will retain working power and interest in life almost to the end.

Death there is no evading: it must be faced, and it must always be to some extent a tragedy. It is a tragedy to think that this wonderful body of ours, that can do so much, that has been filled with youth, and hope, and love, must one day lie in cold corruption, and rot. It came forth to a marvellous world, to a marvellous heritage of beauty and wisdom. It has walked amid roses; it has climbed mountains; it has crossed oceans; it has gazed

upon the stars; it has fought, and worked, and loved; it has been strong, and full of joy of living, but worms will one day wander in the red chambers of its heart.

Even as a great machine, is it not a tragedy that a body should decay, and fall into wrack and ruin?

A little red spider—I don't know its name or species—ran across my page just now. It was little larger than the dot of an 'i.' Its legs were so minute that I could hardly see them, but they twinkled along, and it ran easily and steadily across the paper. I put my pen in front of it; it stopped and then ran round it. I blew; it grasped the paper and held on. What a marvel was there! What nerve and muscle co-ordination in these almost invisible legs to enable them to move in time, and run, and stop, and turn. It takes some skill to time the explosions in the cylinders of a six-cylinder engine. But the nerve explosions that moved these little legs were most exquisitely timed. (By the selection of casual variations, say the Darwinians!) I thought of all this, and I had not heart to kill it. But death—death will kill it without compunction, death daily destroys millions and millions of such wonderful machines. Death will destroy that young infant sucking at its mother's breast. Death will destroy that beautiful woman with the radiant eyes. Death will destroy that great man with the wise brain and the loving heart. Death will destroy us all—sometimes cruelly and sometimes kindly.

In the great War, millions of young men, each an organic miracle, each with a beating heart

and a throbbing brain; each with a marvellous body, the result of millions of years of evolution, have gone forth to battle and forth to death. In a moment the red heart has ceased to beat; the throbbing brain has ceased to think, and the wonderful and beautiful body, with its almost infinite faculties and capacities, has become a corpse—has become carrion.

What are we to make of it?

We can only meet Mystery with Mystery. The same Power that made so wondrously and skilfully is the Power that destroys. From the beginning to the end—from the flaming fire-mist to the rotting corruption—He has been at work. And He who made Love and Beauty can be trusted:

> 'Upon the breast that made the rose shall we with
> shuddering fall?'

Nor can death be the destruction it seems to be. When our finite minds try to fathom infinite mysteries we get lost and bewildered; but this we know: that In the Beginning was the Word—that the Thought in some way preceded the thing and produced the thing—that all things are in some way but a manifestation of Force, or, if we choose to put it so, as a Manifestation of Him from Whom all things proceed. We know, too, that all things known to us—colour, and sound, and shape, and solidity, the neurons and the microbes, and everything else, have existence only in the knowing mind. And we cannot believe that the Power that makes us know such things and see such things, can vanish with the seeming abolition of the phenomena it produced. I speak,

and the vibration in the air my voice makes dies away into silence; but *I* am still here, and my I can still, if I will, produce the same vibrations. And so in the sense The Word spake, and though its music may die away, the Soul behind the Word is still there.

These are but broken glimpses, incoherent fragments of the truth; but such glimpses and such fragments are enough to save us from despair, and to give us a belief that death may be the portal to a fuller life.

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